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CHEMICAL MUNITION DECISION METHODS FOR THE VECTOR-IN-COMMANDER COMBAT SIMULATION

by

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This thesis develops decision logic for the employment of chemical artillery munitions for use in the U.S. Army's Vector-in-Commander (VIC) Combat Simulation. There are three parts to this thesis. The first part uses VIC's "current State" decision methodology to produce an immediately usable improvement to VIC. This part can be used to write the code necessary for incorporation into VIC. The second part uses the "future state" Generalized Value System (GVS) decision methodology. The third part is a stand alone document which identifies, explains, and contrasts the theoretical "underpinnings" of the VIC decision methodology and the GVS decision methodology. Keywords: Chemical warfare munitions, Theses, Combat simulation, chemical weapons, Combat Readiness. (JES)

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Chemical Munition Decision Methods For The Vector-In-Commander Combat Simulation

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ABSTRACT

This thesis develops decision logic for the employment of chemical artillery munitions for use in the U.S. Army's Vector-in-Commander (VIC) Combat Simulation. There are three parts to this thesis. The first part uses VIC's "current state" decision methodology to produce an immediately usable improvement to VIC. This part can be used to write the code necessary for incorporation into VIC. The second part uses the "future state" Generalized Value System (GVS) decision methodology. The third part is a stand alone document which identifies, explains, and contrasts the theoretical "underpinnings" of the VIC decision methodology and the GVS decision methodology.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to improve the representation of chemical warfare in the U.S. Army's Vector-in-Commander (VIC) Combat Simulation. Pursuant to that aim, a chemical operations modeling overview was conducted to identify thesis candidate areas. The results of that overview are presented in Figure I-1. The candidate area advanced by this thesis is the model development of decision logic for the employment of chemical artillery munitions.

This effort uses two methodologies previously explored in theses at the Naval Postgraduate School. First, the Generalized Value System (GVS) developed by Kilmer [Ref. 1] provided a basis for determining the value or worth of entities on the battlefield. Second, the Planning Process by Fletcher [Ref. 2] demonstrated the use of GVS for making tactical decisions.

B. GOALS

This thesis has three goals. The first goal is an immediately usable improvement to VIC in the form of a product which the "model owner", U.S. Army TRADOC Analysis Command--White Sands Missile Range (TRAC-WSMR), can use to

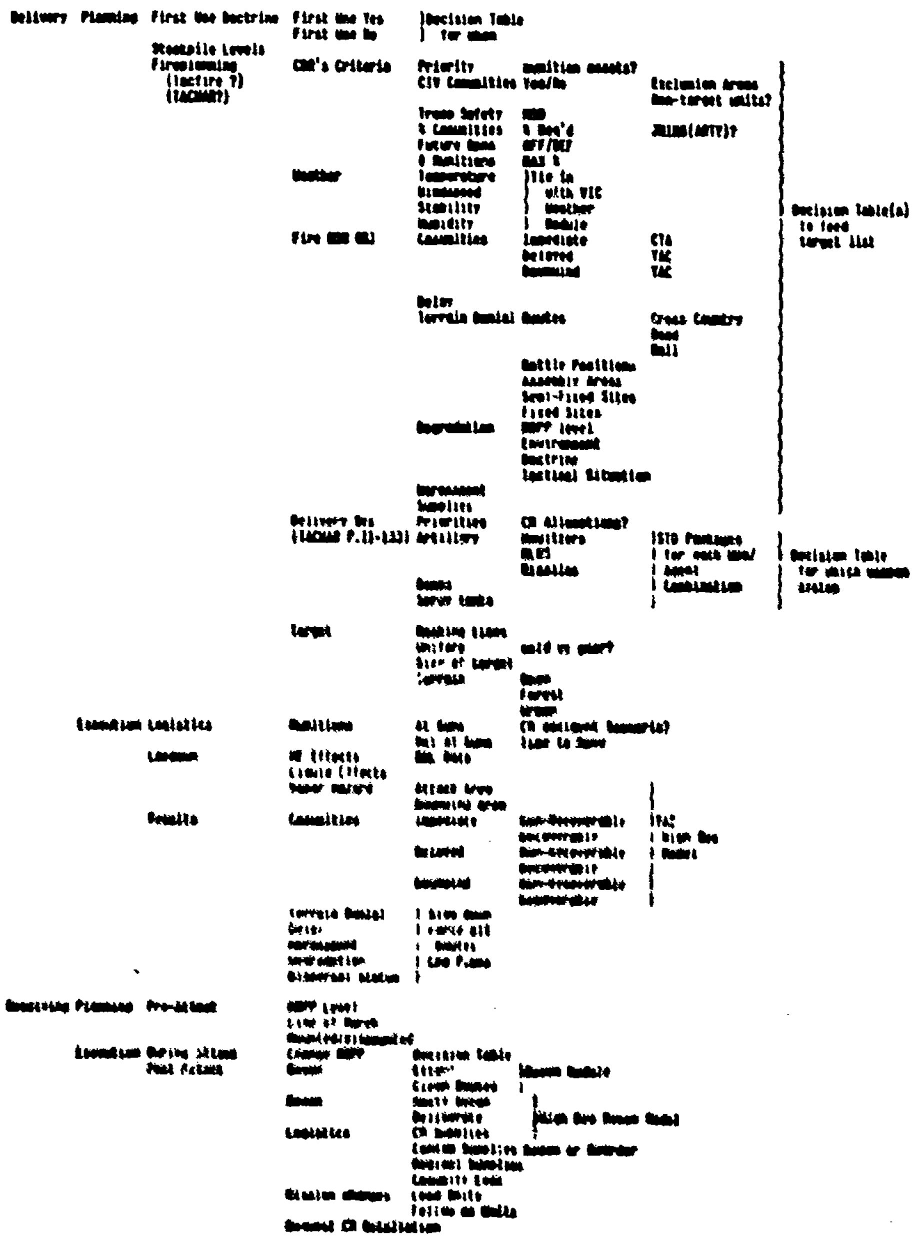

Figure I-1. Chemical Modeling Overview

write the code necessary for incorporation into VIC. Chapter III addresses this first goal. The second goal is to illustrate how GVS can be used for making artillery munition decisions within VIC. This second goal stems from the current consideration being given to incorporating GVS into VIC. Chapter IV addresses this second goal. The third goal is to produce a stand alone document which identifies, explains, and contrasts the theoretical "underpinnings" of the Vector-In-Commander (VIC) decision methodology and the Generalized Value System (GVS) decision methodology. Appendix A addresses this third and last goal.

C. PROCEDURES FOR ACHIEVING GOALS

VIC decision methodology is an example of "current state decision making". Current state decision making is used in almost all combat models. Decisions made by the model are based on the situation when the decision is made. No attempt is made to predict future conditions. Since VIC is designed to have its decision logic expanded as required, the procedures for achieving the first goal of this thesis will follow those described in the Vector-In-Commander (VIC) Combat Simulation DATA INPUT AND METHODOLOGY MANUAL [Ref. 3].

In contrast, the GVS decision methodology is "future state decision making". This methodology is being developed as part of the Air Land Advanced Research Model (ALARM) at the Naval Postgraduate School (NPS) [Ref. 1 & 2]. Each decision made by a GVS model is based on the predicted results of the available courses of action, not on the situation at the time the decision is made. The procedure for illustrating GVS's applicability for making artillery munition decisions will involve adapting the GVS methodology developed by Kilmer [Ref. 1] and used by Fletcher [Ref. 2].

D. SCOPE

The decision logic for the employment of chemical artillery munitions is interrelated with the more general question of decision logic for artillery munitions as a whole. For this reason, where possible, the overall scope of this thesis addresses the decision logic for those artillery munitions explicitly represented in VIC.

The scope of the VIC improvement goal within this thesis is limited to a generic decision logic applicable to both Red and Blue forces. It is anticipated that the differences in Red force doctrine will eventually cause separate Blue and Red decision logic to be developed.

The scope of the GVS methodology demonstration goal includes both Red and Blue forces. Separate treatment is not required.

The scope of the theoretical "underpinnings" goal covers Game Theory, Multiattribute Decision Theory, Utility Theory, and Forcasting Theory.

II. BACKGROUND

A. CHEMICAL WEAPONS AND EFFECTS MODELING

The United States' unilateral national policy concerning chemical weapons is "no first use". When that policy went into effect, chemical weapons had not been used to any significant degree sinc World War I. Steps were even instigated to disband the U.S. Army Chemical Corps. Understandably, chemical weapons and effects modeling had a very low priority during this time. As the military modeling community developed lard combat models, chemical weapons and effects were not included.

However, at about the time when the Chemical Corps disbandment was almost complete, it was discovered that chemical weapons were being used extensively in Southeast Asia. Somewhat later, it was determined that the U.S.S.R. was using chemical weapons routinely against the "Afghanistan rebels". It was also determined that the U.S.S.R force structure and doctrine in the European theater called for the routine and massive use of chemical weapons. This put the U.S. in a position of playing "catch up".

Very slowly, the Chemical Corps has been, and still continues to be, rebuilt. Doctrine on chemical operations has been in a continual state of change as the threat was balanced against the U.S. capabilities and weaknesses.

However, even as this "catch up" progressed, very little was done to update land combat models to include chemical weapons and effects.

This serious shortcoming still persists today. There is currently no model which can simulate force on force engagements with a realistic portrayal of chemical weapons and effects. Without such a model, the Army's ability to evaluate the impact of doctrine and chemical equipment changes is dangerously limited.

B. VIC

1. General

The Army Model Improvement Program (AMIP) consists of a set of combat models which the Army is committed to maintaining and improving. This set consists of a complete hierarchy of combat models from the very high resolution level to the very aggregated level. Each succeedingly more aggregated level in the hierarchy is "fed" data by the less aggregated-higher resolution model below it. The importance of VIC lies in its unique position as the corps level model in the AMIP. As such, VIC is the feeder model for FORCEM, FORCEM being the theater level model in the AMIP.

The following is a brief description of VIC from the VIC Executive Summary [Ref. 4:p. 1]:

> The Vector-in-Commander (VIC) model is a two-sided deterministic simulation of combat in a combined arms environment representing land and air forces at the US

Army corps level with a commensurate enemy force in a mid-intensity battle. The model is designed to provide a balanced representation of major force elements in a tactical campaign of a US Army corps operating in the field in a theater of operations.

VIC became the subject of this thesis because its chemical module has long been identified as requiring the attention of analysts who are also specialists in chemical operations. However, VIC consists of approximately 1 million bytes of computer code (in Simscript II.5, which is not normally taught or used at NPS) and nearly 12 million bytes of data. This large a learning curve prohibits changes to VIC to occur within the scope of a single thesis.

2. Decision Methodology

VIC uses a decision table structure for making internal (i.e., "no man in the loop") decisions as a scenario proceeds. This structure is a set of conditions and a set of actions built into a complex set of "if...then..." statements in the form of a table. For example, consider VIC Decision Table D1 [REF. 5] presented in Figure II-1.

```
D1      RED FLOT RGT INACTIVE 3 2 4

C19     Y    Y    //**IS THIS A 1ST ECH UNIT?
C46     Y    -    //**HAS SYNCH TIME AT LAST LOC BEEN MET?
C651    .0   -    //**HAVE WE SIMULATED >... DAYS?

A14     X    -    //**ATTACK
A1005   X    -    //**ACCESS DECISION TABLE 5
```

Figure II-1. VIC Decision Table D1 [REF. 5]

A Red regiment on the forward line of troops with an inactive status will cause Table D1 to be accessed. The table conditions are then examined columnwise until a column is found that matches the current situation. The actions in that column are then executed and the table is exited.

Specifically above, <u>if</u> the entity is a first echelon unit <u>and</u> the entity meets the synchronization time at its last location <u>and</u> the model has simulated greater than 0.0 days, <u>then</u> the regiment's status will be changed to attack (i.e., ordered to attack) and Decision Table D5 RED FLOT RGT ATTACK will be accessed.

An exception to the usual column-match and exit routine is when action A999 CONTINUE SCAN is one of the actions in the matched column. In that case, the columnwise search will continue with possibly more actions executed if another match is made. If no column is matched, the table is exited with no new actions initiated.

The version of VIC used for this thesis had 92 decision tables constructed from 238 conditions and 143 actions. Unfortunately for anyone attempting to "read" these tables, the comment lines included in the above example are not present in the standard table listing, but were in separate condition and action listings. This gives the task of learning to read VIC decision tables a very long and tedious learning curve.

3. Chemical Representation

The chemical module currently resident in VIC is severely limited by many serious shortcomings. The module was authored in a span of a six week Naval Postgraduate School "Experience Tour" as a last minute attempt to include chemical operations in a major study then underway. The original author, CPT John Van Grouw, despite his not being a chemical officer, provided an excellent basic structure upon which those who follow can build and improve.

This thesis will partially address one of VIC's shortcomings, the absence of chemical operations from the VIC decision logic. Currently, decision tables cannot initiate chemical attacks nor can decision tables be affected by chemical conditions. To realistically portray chemical operations, this disconnect must be corrected.

C. THE GENERALIZED VALUE SYSTEM (GVS)

The GVS methodology basically consists of a way of calculating the combined "value" of all the entities in a sector for each side. This value is a function of the availability of different type entities in the sector, those entity's capabilities, their assigned missions, and their proximity in time to performing those assigned missions. The sector situation is represented by a pair of "value curves"--a Blue value-vs-time curve and a Red value-vs-time curve.

The value curves described above extend from the current time out to the end of the commander's "decision horizon", defined in hours according to the level of command. Within this thesis, a combat sector is defined as "infeasible" if the commander's value curve falls below the enemy's value curve any time during the decision horizon. The commander's goal is to always be feasible. Once infeasible, the commander must compare the courses of action available to him and decide which to implement.

In the optimal GVS decision method, the commander would calculate a revised pair of value curves for each available course of action. Then, using one or more measures of effectiveness, one course of action is selected for implementation. If no available course of action meets the selected measure(s) of effectiveness, a request for additional resources is made to the next level of command and the process continues at that level.

Because calculating a pair of value curves for every available course of action is usually computationally prohibitive, a sub-optimal decision method is to compute a pair of value curves for N courses of action and select the "best" by applying the selected measure(s) of effectiveness.

Within this thesis, two measures of effectiveness will be used. The first measure of effectiveness is feasibility restoration. That is, if by varying the time of execution, a course of action cannot restore feasibility, that course of action is eliminated. The second measure of effectiveness is the difference between the two value curves at the end of the decision horizon. The course of action with the greatest difference in value at the end of the decision horizon is the optimum course of action.

III. MUNITION SELECTION WITH VIC DECISION LOGIC

A. WORKING DEFINITIONS

The decision of when to use chemical munitions is actually a decision of when to fire chemical munitions in place of other munitions. It follows that any decision apparatus which decides on chemical munition use must also consider non-chemical munitions. Hence, discussion on the subject must be able to distinguish differences between various munitions. The following definitions are presented to facilitate that discussion:

Standard effects: suppression, neutralization, and destruction (VIC battle damage criteria) [Ref. 3:p. 4-6], all of which are subsets of one type of effect: attrition.

Standard munition: attrition munitions.

Special effects: an important tactical effect which does not fit the standard effects of artillery target damage criteria. Examples: delaying, degrading, channelizing, and/or disrupting.

Special munition: a munition, not necessarily limited to artillery, which produces one or more special effects. This munition may or may not also produce standard effects.

Munition Category: a set of munitions with similar effect(s).

B. ANALYSIS OF CURRENT VIC ARTILLERY MODULE

Considering the above definitions, VIC explicitly portrays six munition categories, five of which are special munitions. They are:

- Standard munitions
- Non-persistent chemical munitions
- Persistent chemical munitions
- Smoke munitions
- Mine munitions
- Jammer munitions

The VIC Artillery Module (AT) uses fourteen data input "segments". Each of these segments inputs the data necessary for representing a specific aspect of the artillery activities simulated by VIC. Of these fourteen, the following five require consideration for the representation of a munitions selection process:

- AT-THREE-ZERO Munition Data
- AT-FOUR Special Munition "Mission" Data
- AT-FIVE Number of Rounds to Service
- AT-SIX Preferred Munition Type
- AT-SEVEN Target Priority

These five segments have the following representation of special munitions [Ref. 3]:

1. AT-THREE-ZERO

Types of data common to all munition types are input in this segment. Data peculiar to special munitions are input in their respective modules.

2. AT-FOUR

Special munitions are defined into "missions" in this segment; standard munitions are never defined into missions. The main distinction defined here is which mission type is to be used against which unit prototype.

3. **AT-FIVE**

Special munition mission types are equated with target classes in this segment. As such, this segment defines:

For special munitions--the number of rounds required to service a mission type.

For standard munitions--the number of rounds required to service a particular target class.

Since AT-FOUR defines which mission type is used against which unit prototype, this segment does define the number of special munition rounds required to service a particular unit prototype.

4. **AT-SIX**

Special munition mission types are also equated with target classes in this segment. As such, this segment:

For special munitions--defines which special munition is used for each mission type.

For standard munitions--ranks standard munitions in the order of preference to be used against each target class.

The overall purpose of this segment is munition choice given target class. Since mission types are equated with target classes, there is no attempt to model the choice between standard and special munitions.

5. AT-SEVEN

Special munition mission types are equated with unit prototypes in this segment. Thus, special munition mission types are prioritized with (i.e., compete against) unit prototypes for the priority of engagement as determined in a firing unit's target list. In other words, the fact that it is a particular special munition mission, not what the target is or the effect on that target, is the criteria by which all artillery units prioritize their target lists when dealing with special munitions.

C. PROBLEMS IN THE CURRENT VIC ARTILLERY MODULE

The preceding discussion illustrates two major shortcomings. The first is a model structure that does not explicitly choose between special munitions and standard munitions. The second is a model structure which prioritizes target lists by munition type for special munitions on one hand and by target class for standard munitions on the other. On the battlefield, target priority is a function of target importance (i.e., target class); it is not a function of the munition type as is used with special munitions.

D. CHANGES TO THE CURRENT VIC ARTILLERY MODULE

Because of the way segments AT-THREE through AT-SEVEN build upon each other, changes must start at AT-THREE and be carried through AT-SEVEN. The required changes are treated in two parts. First, they are identified and discussed in the following section under the heading of General Changes. Second, the explicit details of what, where, and how to effect the changes are covered under the heading of Detailed Changes. As discussed in the introduction, the level of detail does not include computer code changes. It is intended that the level of detail given will be sufficient to enable a VIC programmer to make the necessary computer code changes.

1. General Changes

a. AT-THREE-ZERO

Add "MUNITION CATEGORY" as an input for each munition type, so that segment AT-SIX can rank munitions within the same category.

b. AT-FOUR

Remove the "mission" concept and convert all data to munition data. The use of special munition missions is a complication detrimental to modeling the choice between munition categories.

c. AT-FIVE

With AT-FOUR changed as indicated above and missions no longer in use, this segment will take on the same meaning for both special and standard munitions (i.e., the number of rounds to service a particular target class).

d. AT-SIX

The choice between standard and special munitions cannot be made by the method currently used with standard munitions (i.e., a simple rank ordering of special and standard munitions together for each target class). This would be equivalent to ranking "apples and oranges". This would also result in special munitions being selected only when higher ranked munitions could not be used.

However, ranking munitions which have similar effects (i.e., within munition categories) is reasonable. Standard munitions attrite the target and can be ranked by which provides the greater attrition level. The same applies to each of the other munition categories. To effect this change, this segment should input the "within munition category" rankings for each target unit prototype.

Given this "within munition category" ranking, a method is needed by which VIC can model the choice between categories. Within VIC, the logical choice is to modify current decision tables and/or develop new decision table(s) which decide munition category based on the tactical situation. This will correct the first major shortcoming discussed earlier.

f. AT-SEVEN

With the changes listed above implemented, this segment should now prioritize target lists strictly on the basis of target unit prototypes. This result corrects the second major shortcoming discussed earlier.

2. Detailed Changes

Some of following change descriptions include definitions, wordage, and format found in the Vector-In-Commander (VIC) Combat Simulation DATA INPUT AND METHODOLOGY MANUAL [Ref. 3]. Quotes and offset are purposely not used because they disrupt the flow of presentation and understanding.

a. AT-THREE

Add CATEGORY OF MUNITION (after "NAME OF MUNITION"). This value categorizes each munition by it's effects. The following represents the key for the categories considered by this thesis:

0	Standard munitions
1	Non-persistent chemical munitions
2	Persistent chemical munitions
3	Smoke munitions
4	Mine munitions
5	Jammer munitions

b. AT-FOUR

First, redefine "mission" to mean any artillery fire mission (i.e., the servicing of one target during an artillery allocation cycle). Using this definition, this segment should input the following:

NUMBER OF SPECIAL MUNITION TYPES--The number of artillery special munition types.

(iterate for each special munition type)

NAME OF SPECIAL MUNITION--A short name to identify the munition/ordnance used in the database. This name must match the name in AT-THREE-ZERO, in the respective special munition module, and in logistics module (if logistics is being played).

ENEMY OFFSET--Distance, from the front of the target unit's leading elements to the mission's aim point. If this is a chemical munition (category 1 or 2), this is the distance from the target's center of mass to the mission's aim point. A "tie-in" with wind direction should eventually be included in this offset distance.

FRIENDLY OFFSET--This is the same as ENEMY OFFSET, but is measured from the friendly unit's leading elements.

MISSION WINDOW FOR OFFENSIVE USE OF THIS MUNITION--If the using side is on the offensive and if their artillery cannot get the mission delivered by the time this window time has passed, the mission will be dropped.

MISSION WINDOW FOR DEFENSIVE USE OF THIS MUNITION--This is the same as MISSION WINDOW FOR OFFENSIVE USE OF THIS MUNITION, except that it applies when the using side is on the defense.

The iteration on GROUND UNIT PROTOTYPE, as the current segment requires, is no longer needed in this segment. The decision of which category of munition, and of which munition within that category, is decided using segment AT-SIX inputs and the decision tables.

c. AT-FIVE

No format changes are required, but the number of special munitions rounds required to service each target class is needed. Generating this database is beyond the scope of this thesis.

d. AT-SIX

First, an "AT-SIX" segment for each munition category is needed to preference rank munitions within their respective categories. The format currently used in AT-SIX requires no changes. The following segments would suffice for the categories being considered by this thesis:

AT-SIX-ZERO	Standard munitions
AT-SIX-ONE	Non-persistent chemical munitions
AT-SIX-TWO	Persistent chemical munitions
AT-SIX-THREE	Smoke munitions
AT-SIX-FOUR	Mine munitions
AT-SIX-FIVE	Jammer munitions

Next, with all munitions separated into categories and preference ranked within those categories, the choice of munition is required (i.e., which category should service different tactical situations). To do this requires modification of the current decision tables and/or the development of new decision table(s).

(1) Decision Table Modification Candidates. Decision Tables deemed likely modification candidates are listed in TABLE III-1. Candidates were selected by including all tables which currently cause at least one special munition to be requested. Added to this list were any remaining tables that appeared to play a direct role in combat operations. In all, 35 decision tables were selected.

(2) Examination of Current Conditions and Actions. Examination of the current 238 conditions revealed that there are no conditions directly related to special munitions. Examination of the current 143 actions found the following actions directly related to special munitions:

A54 Request Smoke for self screening
A55 Request Smoke for enemy screening
A56 Request FASCAM for self protection
A57 Request FASCAM for enemy blocking
A58 Request FASCAM for reinforcement blocking

The existence of actions requesting smoke and FASCAM caused two modeling options to become apparent. One option was to maintain the current structure and create actions for chemical and jammer munitions similar to those for smoke and FASCAM, inserting these actions into the relevant decision tables. The second option was to create an action which accesses a special munition decision table when conditions indicate a special munition might be

TABLE III-1. DECISION TABLE MODIFICATION CANDIDATES

Table #	Table Title	Action #	Action Title
D1	RED FLOT RGT INACTIVE	NONE	
D2	RED FLOT RGT DEFEND	A54	SMOKE FOR SELF SCREENING
D2	RED FLOT RGT DEFEND	A55	SMOKE FOR ENEMY SCREENING
D3	RED FLOT RGT WITHDRAWING	A54	SMOKE FOR SELF SCREENING
D4	RED FLOT RGT PURSUE	A57	FASCAM FOR ENEMY BLOCKING
D5	RED FLOT RGT ATTACK	NONE	
D7	RED FLOT RGT MOVE TO CONTACT	A55	SMOKE FOR ENEMY SCREENING
D7.5	RED FLOT RGT HASTY DEFEND	A54	SMOKE FOR SELF SCREENING
D7.5	RED FLOT RGT HASTY DEFEND	A55	SMOKE FOR ENEMY SCREENING
D9	RED FLOT REGT ASSAULT	NONE	
D10	RED FLOT ADVANCE GUARD	NONE	
D11	RED 2ND ECH RGT OF ANY DIV	A55	SMOKE FOR ENEMY SCREENING
D12	RED 2ND ECH RGT PASSING THRU	A55	SMOKE FOR ENEMY SCREENING
D16	RED FLOT DIV HQ	A58	FASCAM FOR REINFORCEMENT BLOCKING
D17	RED FLOT DIV MOVE & COMMIT 2ND ECH RGTS	A57	FASCAM FOR ENEMY BLOCKING
D21	RED 1ST ECH RGT OF 2ND ECH DIV PASSING THRU	A55	SMOKE FOR ENEMY SCREENING
D31	1ST ECH RGT OF 1ST ECH DIV OF 2ND ECH ARMY PASSING THRU	A55	SMOKE FOR ENEMY SCREENING
D42	RED OMG 1ST ECH BDE DEFEND	A54	SMOKE FOR SELF SCREENING
D42	RED OMG 1ST ECH BDE DEFEND	A55	SMOKE FOR ENEMY SCREENING
D43	RED OMG 1ST ECH BDE WITHDRAWING	A54	SMOKE FOR SELF SCREENING
D44	RED OMG 1ST ECH BDE PURSUE	A57	FASCAM FOR ENEMY BLOCKING
D45	RED OMG 1ST ECH BDE ATTACK	NONE	
D46	RED OMG ADVANCE GUARD	NONE	
D47	RED OMG 2ND ECH BDE	A55	SMOKE FOR ENEMY SCREENING
D48	RED OMG 2ND ECH BDE PASSING THRU	A55	SMOKE FOR ENEMY SCREENING
D49	RED OMG 1ST ECH BDE MOVE TO CONTACT	A55	SMOKE FOR ENEMY SCREENING
D50	RED OMG CORPS HQ	A58	FASCAM FOR REINFORCEMENT BLOCKING
D51	RED OMG CORPS MOVE & COMMIT 2ND ECH BDES	A57	FASCAM FOR ENEMY BLOCKING
D54	RED OMG ASSAULT	NONE	
D102	BLUE MBA BATTALION DEFEND	A54	SMOKE FOR SELF SCREENING
D102	BLUE MBA BATTALION DEFEND	A56	FASCAM FOR SEL PROTECTION
D103	BLUE MBA BATTALION WITHDRAWING	A54	SMOKE FOR SELF SCREENING
D104	BLUE MBA BATTALION PURSUE	NONE	
D105	BLUE MBA BATTALION ATTACK	NONE	
D106	BLUE MBA BATTALION DELAY	A54	SMOKE FOR SELF SCREENING
D106	BLUE MBA BATTALION DELAY	A56	FASCAM FOR SEL PROTECTION
D107	BLUE BMA BATTALION MOVEMENT TO CONTACT	NONE	
D109	BLUE MBA BATTALION ASSAULT	NONE	
D110	BLUE CFA MANEUVER UNIT	A54	SMOKE FOR SELF SCREENING
D110	BLUE CFA MANEUVER UNIT	A56	FASCAM FOR SEL PROTECTION
D117	BLUE MBA BDE CONTROLLING BATTALIONS	A55	SMOKE FOR ENEMY SCREENING
D117	BLUE MBA BDE CONTROLLING BATTALIONS	A57	FASCAM FOR ENEMY BLOCKING

appropriate. This special munition decision table would decide munition types for given situations. The second approach is favored because of its easier maintainability. Should munition selection criteria changes be required or new special munitions be added, only the table itself need be changed.

(3) **Examination of the Decision Table Modification Candidates.** To build the special munitions decision table it is necessary to determine the required conditions and actions. Some of the conditions are currently already in VIC. To find these, an examination of the 35 previously selected tables was conducted, table by table, noting any relevant current conditions and any required new conditions. During the examination, any necessary modifications for each table were also determined. The results of this examination are presented in Appendix B. More useful is a consolidation of the information in Appendix B presented in TABLE III-2, where each condition is listed once with its description, answer/thresholds, and any links with other conditions. These links were from the tables themselves or were implied by the table's resulting actions.

(4) **The Special Munition Decision Table.** In addition to the current conditions presented in TABLE III-2,

TABLE III-2. DECISION TABLE EXAMINATION RESULTS

C#	ABREV CONDITION TITLE	ANSW	LINKS
C1	IS THIS UNIT ENGAGED?	Y	oC19 oC402 oC403 oC405 oC414
C11	RNG IN KM TO NEAREST OPPONENT (...?	.3	
C19	IS THIS A FIRST ECH UNIT?	Y	oC1, &C58 &C613
C37	IS THE CFA BATTLE OVER?	Y	&C415
C58	APPROACH REINFRCMNT IN TA & (... KM FROM RED FLOT?	15	&C19 &C613
C74	IS THERE AN ADV GRD FOR THIS UNIT?	Y	&C75 &C203
C75	UNIT'S ADV GRD FORCE RATIO (R/B))=...?	3	&C74 &203
C203	UNIT (... KM BEHIND LEADING UNIT?	5	&C74 &C75
C402	COMBAT STATUS = ADVANCE UNOPPOSED?	Y	oC1
C403	COMBAT STATUS = FNT DEL ATK?	Y	oC1 oC404 oC405 oC414 oC409 oC410 oC411 oC412 oC413
C404	COMBAT STATUS = PURSUE?	Y	oC1 oC403 oC405 oC409 oC410 oC411 oC412 oC413
C405	COMBAT STATUS = FNT COUNTER ATK?	Y	oC1 oC403 oC404 oC409 oC410 oC411 oC412 oC413 oC414
C406	COMBAT STATUS = ASSUALT	Y	oC410 oC414
C409	COMBAT STATUS = FNT DEL DEF?	Y	oC403 oC404 C405 oC411 oC412 oC413
C410	COMBAT STATUS = MOVEMENT TO CONTACT?	Y	oC1 oC403 oC404 oC405 oC406 oC414
C411	COMBAT STATUS = FNT HASTY DEF?	Y	oC403 oC404 oC405 oC409 oC412 oC413
C412	COMBAT STATUS = FLK HASTY DEF?	Y	oC403 oC404 oC405 oC409 oC411 oC413
C413	COMBAT STATUS = DELAY (ACT DEF)?	Y	oC403 oC404 oC405 oC409 oC411 oC412
C414	COMBAT STATUS = WITHDRAW OPPOSED?	Y	oC1 oC403 oC405 oC406 oC410
C415	COMBAT STATUS = WITHDRAW UNOPPOSED?	Y	(by itself), &C37
C602	IS THIS AN INF UNIT?	Y	
C613	TANK, MECH INF, AIRBORNE, OR CAV UNIT?	Y	&C19 &C58

KEY: '&' - Means Logical 'and', i.e. both conditions must be met.
'o' - Means Logical 'or', i.e. either condition must be met.

development of the special munition decision table required some new conditions. Specifically:

```
C700    HAS THE TARGET UNIT'S SIDE USED CHEMICALS?  (Y/N)
C701    DOES THIS UNIT HAVE CHEMICAL RELEASE?  (Y/N)
C702    IS THE REQUESTING UNIT IN MOPP 3 OR MOPP 4?  (Y/N)
C703    IS THE TARGET UNIT IN MOPP 3 OR MOPP 4?  (Y/N)
C704    UNIT'S DEFENSIVE POSITION STATUS = DEFENSIVE? (Y/N)
```

Some new actions were also needed. First, to keep all special munitions actions grouped together, actions A54 through A58 became:

```
A701    REQUEST SMOKE FOR SELF SCREENING
A702    REQUEST SMOKE FOR ENEMY SCREENING
A703    REQUEST FASCAM FOR SELF PROTECTION
A704    REQUEST FASCAM FOR ENEMY BLOCKING
A705    REQUEST FASCAM FOR REINFORCEMENT BLOCKING
```

Secondly, the following actions were added:

```
A700    ACCESS D200, SPECIAL MUNITION DECISION TABLE
A706    REQUEST NON-PERSISTENT CHEMICAL ATTACK
A707    REQUEST PERSISTENT CHEMICAL ATTACK
A708    REQUEST JAMMER EMPLACEMENT
A709    USE STANDARD MUNITIONS ONLY
A710    REQUEST CHEMICAL RELEASE
```

With the above actions and conditions, it is now possible to build an "empty" special munitions decision table. Figure III-1 presents this empty table. Next it is necessary to develop the columnwise "situations" in order to "fill in" the table. This situation development was performed by translating the doctrine for the employment of different munition categories into general guidelines as a

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	CONDITION/ACTION TITLE
C1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS UNIT ENGAGED (DIRECT FIRE)?
C10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS RANGE IN KM TO NEAREST OPPONENT)=...?
C11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS RANGE IN KM TO NEAREST OPPONENT (...?
C19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS A FIRST ECH UNIT?
C37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THE CFA BATTLE OVER?
C58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS AN APPROACHING REINFORCEMENT IN TA & (... KM FROM RED FLOT?
C74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THERE AN ADVANCE GUARD FOR THIS UNIT?
C75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S ADVANCE GUARD'S FORCE RATIO (R/B))=...?
C204	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT) ... KM BEHIND LEADING UNIT?
C402	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT's COMBAT STATUS = ADVANCE UNOPPOSED?
C403	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = FNT DELIBERATE ATTACK?
C404	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = PURSUE?
C405	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = FRONTAL COUNTER ATTACK?
C406	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = ASSUALT?
C409	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = FNT DELIBERATE DEF?
C410	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = MOVEMENT TO CONTACT?
C411	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = FRONTAL HASTY DEFENSE?
C412	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = FLANK HASTY DEFENSE?
C413	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = DELAY (ACTIVE DEFENSE)?
C414	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = WITHDRAW OPPOSED?
C415	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = WITHDRAW UNOPPOSED?
C602	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS AN INFANTRY UNIT?
C613	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS A TANK MECH INFANTRY AIRBORNE OR CAV UNIT?
C700	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	HAS THE TARGET UNIT'S SIDE USED CHEMICALS?
C701	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	DOES THIS UNIT HAVE CHEMICAL RELEASE?
C702	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT IN MOPP 3 OR MOPP 4?
C703	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THE TARGET UNIT IN MOPP3 OR MOPP4?
C704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT'S DEF POSITION STATUS = DEFENSIVE?
A701	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY SMOKE FOR SELF SCREENING
A702	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY SMOKE FOR ENEMY SCREENING
A703	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE FASCAM FOR SELF PROTECTION
A704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE FASCAM FOR ENEMY BLOCKING
A705	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE FASCAM FOR REINFORCEMENT BLOCKING
A706	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY NON-PERSISTENT CHEMICAL ATTACK
A707	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY PERSISTENT CHEMICAL ATTACK
A708	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY JAMMER EMPLACEMENT
A709	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	USE STANDARD MUNITIONS ONLY
A710	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST CHEMICAL RELEASE
A999	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	CONTINUE SCAN

Figure III-1. Empty Special Munition Decision Table

function of the conditions included in the empty table. Such guidelines were alluded to in the VIC Executive Summary as "tactical decision rules" [Ref. 4:pp. 3,5]. Unfortunately, the VIC documentation does not include a definition or listing of these tactical decision rules.

Figure III-2 presents the completed special munition decision table. Excess columns and unused conditions have been removed. The specific numbers used are estimates or were obtained directly from similar applications of the same conditions in the current decision tables. The row for action A708 for jammer emplacement was left empty because no tactical decision rules for jammer munitions were found during the course of this thesis.

The tactical decision rules used to develop the situations can be better understood by referring to the decision flowchart presented in Figure III-3. The flowchart was used to develop 16 "related" situations, specifically situations 7 through 22. As the flowchart implies, these situations are related in the sense that the same questions were asked to determine which munition should be used. Six additional situations were developed based on specific situations. Appendix C discusses and explains all 22 situations explicitly.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	CONDITION/ACTION TITLE
C1	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	IS UNIT ENGAGED (DIRECT FIRE)?
C10	-	-	-	-	-	-	.3	.3	.3	.3	.3	.3	.3	.3	3	3	3	3	3	3	3	3	IS RANGE IN KM TO NEAREST OPPONENT >=...?
C11	-	-	-	-	-	.3	3	3	3	3	3	3	3	3	-	-	-	-	-	-	-	-	IS RANGE IN KM TO NEAREST OPPONENT <...?
C58	-	-	15	15	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	APPROACHING REINFORCEMENT IN TA & <... KM FROM RED FLOT?
C204	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	IS THIS UNIT >= ... KM BEHIND LEADING UNIT?
C404	-	-	-	-	-	-	-	-	N	N	Y	Y	-	-	-	-	N	N	Y	Y	-	-	IS THIS UNIT'S COMBAT STATUS = PURSUE?
C414	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	IS THIS UNIT'S COMBAT STATUS = WITHDRAW OPPOSED?
C700	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	HAS THE TARGET UNIT'S SIDE USED CHEMICALS?
C701	N	-	Y	Y	-	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	DOES THIS UNIT HAVE CHEMICAL RELEASE?
C702	-	-	Y	Y	-	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	IS THIS UNIT IN MOPP 3 OR MOPP 4?
C703	-	-	N	N	-	-	N	-	N	-	N	-	N	-	N	-	N	-	N	-	N	-	IS THE TARGET UNIT IN MOPP3 OR MOPP4?
C704	-	-	N	Y	-	-	Y	-	Y	Y	N	-	N	-	Y	-	Y	Y	N	-	N	-	IS THIS UNIT'S DEF POSITION STATUS = DEFENSIVE?
A701	-	-	-	-	-	-	X	X	-	-	X	X	-	-	X	X	-	-	X	X	-	-	REQUEST IMMEDIATE ARTY SMOKE FOR SELF SCREENING
A702	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	X	X	-	-	X	X	REQUEST IMMEDIATE ARTY SMOKE FOR ENEMY SCREENING
A703	-	-	-	-	-	-	X	X	X	X	-	-	-	-	X	X	X	X	-	-	-	-	REQUEST IMMEDIATE FASCAM FOR SELF PROTECTION
A704	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	X	X	-	-	REQUEST IMMEDIATE FASCAM FOR ENEMY BLOCKING
A705	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE FASCAM FOR REINFORCEMENT BLOCKING
A706	-	-	-	X	-	-	-	-	-	-	X	-	X	-	-	-	-	-	X	-	X	-	REQUEST IMMEDIATE ARTY NON-PERSISTENT CHEMICAL ATTACK
A707	-	-	X	-	-	-	X	-	X	-	-	-	-	-	X	-	X	-	-	-	-	-	REQUEST IMMEDIATE ARTY PERSISTENT CHEMICAL ATTACK
A708	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST IMMEDIATE ARTY JAMMER EMPLACEMENT
A709	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	USE STANDARD MUNITIONS ONLY
A710	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	REQUEST CHEMICAL RELEASE
A999	X	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	CONTINUE SCAN

Figure III-2. Special Munition Decision Table

```
        0<R<.3   STANDARD ONLY
                                                     Y   P-CM, SP-FASCAM, SS-SMOKE       7
                                         Y  WITHDRAW
                                            OPPOSED? N   P-CM, SP-FASCAM                 9
                              Y  CHEMICAL?
                                                     Y   SP-FASCAM, SS-SMOKE             8
                                         N  WITHDRAW
                                            OPPOSED? N   SS-FASCAM                       10
        .3<R<3   DEFENSE?
                                                     Y   NP-CM, EB-FASCAM, SS-SMOKE      11
                                         Y  PURSUING?
                                                     N   NP-CM, SS-SMOKE                 13
                              N  CHEMICAL?
                                                     Y   EB-FASCAM, SS-SMOKE             12
                                         N  PURSUING?
RANGE?                                               N   SS-SMOKE                        14

                                                     Y   P-CM, SP-FASCAM, SS-SMOKE       15
                                         Y  WITHDRAW
                                            OPPOSED? N   P-CM, SP-FASCAM, ES-SMOKE       17
                              Y  CHEMICAL?
                                                     Y   SP-FASCAM, SS-SMOKE             16
                                         N  WITHDRAW
                                            OPPOSED? N   SP-FASCAM, ES-SMOKE             18
        3<R<5    DEFENSE?
                                                     Y   NP-CM, EB-FASCAM, SS-SMOKE      19
                                         Y  PURSUING?
                                                     N   NP-CM, SS-SMOKE                 21
                              N  CHEMICAL?
                                                     Y   EB-FASCAM, SS-SMOKE             20
                                         N  PURSUING?
                                                     N   SS-SMOKE                        22

                        KEY:   Y            Yes
                               N            No
                               P-CM         PERSISTENT CHEMICAL
                               NP-CM        NON-PERSISTENT CHEMICAL
                               SP-FASCAM    SELF PROTECTING FASCAM
                               EB-FASCAM    ENEMY BLOCKING FASCAM
                               SS-SMOKE     SELF SCREENING SMOKE
                               ES-SMOKE     ENEMY SCREENING SMOKE
```

Figure III-3. Situation Flowchart

e. AT-SEVEN

With the changes listed above implemented, this segment should not require any changes.

Figure III-2 represents the finale of the accomplishment of the first goal of this thesis, an immediately usable improvement to VIC in the form of a product which can be used to write the code necessary for incorporation. This does not mean to imply that this product is perfect; but rather, it is an improvement to VIC which must be tested and adjusted according to the results it produces.

IV. MUNITION SELECTION WITH GVS

This section illustrates GVS's ability to accomplish the same munition selection task accomplished by the Special Munition Decision Table developed in Section III. However, the decision criteria used by GVS are far more meaningful and versatile than the tactical decision rules used in the Special Munition Decision Table.

A. ESSENTIAL ASPECTS OF GVS

The following descriptions and definitions are intended to give the reader sufficient understanding of GVS for the application which follows. It is not intended to repeat the more detailed development by Kilmer [Ref. 1].

1. Assumptions

a. Value

"The value of an entity...is dependent on two factors. First, value depends on how useful the entity is...power being the measure of the usefulness of an entity. Secondly, value depends on the supply or availability of the entity." [Ref. 1, p. 26-27] This thesis considers the power of the targeted unit and the power of the "benefitting" unit to be the only measure required for analyzing the effects of different munition types. This is functionally equivalent to Kilmer's [Ref. 1:p. 27] assumption that, as a first order approximation, value is equal to power.

b. Power

"There are two types of power that an entity might (sic) have, inherent and/or derived. Inherent power is the ability to disrupt, delay, or destroy the power of enemy entities." [Ref. 1, p. 26-27] Because artillery entities and the entities they support are inherent power only entities, this thesis does not consider derived power.

c. Discounted Power

"The power of an entity...not ready to execute its assigned mission is a discounted version of the power of that entity if it was ready..." [Ref. 1, p. 26-27] Ready, in this context, means the entity has arrived at a position where it can begin its assigned mission.

2. Definitions

The following definitions are abridged from those given by Kilmer [Ref. 1].

a. Entity--Z1

An entity is anything represented in the model with power (and/or value). Notation: X1, X2, ... for Blue; Y1, Y2, ... for Red; Z1 for a typical entity of either color.

b. State--SZ1(t)

An entity's state is the vector of an entity's attributes at time t. Notation: SZ1(t) is the state of Z1 at time t. The underline is used to denote this is a vector of attributes. Attributes are of two types--quantitative and qualitative. Quantitative attributes are the number/amount of on-hand MTOE vehicles, equipment, supplies, and personnel. Qualitative attributes describe the condition of the entity. Examples of a qualitative attribute are the mission of the entity or the chemical contamination status of the entity.

c. Basic Inherent Power--BIP(Z1)

BIP(Z1) is Z1's inherent power at full MTOE strength, ready to engage its most likely adversary. This is the maximum power an entity can have. The units for power, as initiated by Kilmer [Ref. 1], were "STAPOW". This thesis further shortens this to "SPU" to mean Standard Power Unit.

3. Equations

a. Adjusted Basic Inherent Power

This is the BIP after adjustment for the entity's current state and assigned mission:

$$ABIP(\underline{S}Z1(t)) = f(BIP(Z1), \underline{S}Z1(t))$$

(eqn IV-1)

The nature and form of Equation IV-1 is a user input. Crawford [Ref. 6] has begun the work on this task by developing a relationship between power and the on-hand personnel, ammunition, vehicle, and POL levels.

b. Predicted Adjusted Basic Inherent Power

This is the ABIP predicted for time $t > t_p$ (present time or time of prediction), given the entity's state at t_p. The form of the following equations was proposed by Kilmer [Ref. 1] as a first order approximation:

$$PABIP(t|t_p) = ABIP(t_p) \times \exp[-L_{BA}(t-t_p)] \qquad t_p <= t <= t_A$$

(eqn IV-2)

$$PABIP(t|t_p) = PABIP(t_A|t_p) \times \exp[-L_{AA}(t-t_A)] \qquad t >= t_A$$

(eqn IV-3)

Where: t_A = Time of Arrival, the expected time when the entity will arrive at a position where it can begin its assigned mission; L_{BA} = Before Arrival Decay Constant, calculated from the Percent Change/Hour Before Arrival (P_{BA}); L_{AA} = After Arrival Decay Constant, calculated from the Percent Change/Hour After Arrival (P_{AA}).

Some discussion on the rationale for Equations IV-2 and IV-3 is necessary at this point. Both of these equations represent an exponential decay of power with L_{BA} and L_{AA} as the decay constants. The meaning of these constants is critical to understanding GVS. This area of

GVS still requires further research, but the following is one way of considering these decay constants.

First, since it has already been stated that both decay constants are a function of their respective percent change/hour values, this relationship will be derived. Suppose L is a generic decay constant and P is a generic percent change per hour. The key to this derivation lies in the fact that at time t_p + 1 hour, a percent change equal to P will occur, so PABIP = ABIP x (1-P/100). This allows the ABIP to be canceled from both sides of the equation. Thus, substituting $t = t_p + 1$ and $PABIP(t_p+1 | t_p) = ABIP(t_p) \times (1-P/100)$ into Equation IV-2 will yield the following result:

$$PABIP(t|t_p) = ABIP(t_p) \times \exp[-L(t-t_p)]$$

$$PABIP(t_p+1|t_p) = ABIP(t_p) \times \exp[-L(t_p+1-t_p)]$$

$$ABIP(t_p) \times (1-P/100) = ABIP(t_p) \times \exp[-L]$$

$$(1-P/100) = \exp[-L]$$

$$\ln(1-P/100) = \ln(\exp[-L])$$

$$\Longrightarrow \ln(1-P/100) = -L$$

$$\Longrightarrow L = -\ln(1-P/100)$$

(eqn IV-4)

Second, the meaning of P_{BA} and P_{AA} need to be clarified. The power of an inherent power (i.e., combat) entity changes over time even before arrival at the position where it begins its mission (i.e., engages the enemy with its organic weapons). This change is due to: before arrival supplies usage (P_{BASU}), before arrival supplies replenishment (P_{BASR}), before arrival noncombat personnel attrition (P_{BANPA}), before arrival indirect fire personnel attrition (P_{BAIPA}), and before arrival personnel replenishment (P_{BAPR}). P_{BA} is a aggregation of all the above before arrival percent changes:

$$P_{BA} = - P_{BASU} + P_{BASR} - P_{BANPA} - P_{BAIPA} + P_{BAPR} \qquad \text{(eqn IV-5)}$$

Similarly, the change in power after arrival is due to after arrival supplies usage (P_{AASU}), after arrival supplies replenishment (P_{AASR}), after arrival combat personnel attrition (P_{AACPA}), after arrival indirect fire personnel attrition (P_{AAIPA}), and after arrival personnel replenishment (P_{AAPR}). Like P_{BA}, P_{AA} is also an aggregation of the after arrival percent changes:

$$P_{AA} = - P_{AASU} + P_{AASR} - P_{AACPA} - P_{AAIPA} + P_{AAPR} \qquad \text{(eqn IV-6)}$$

The bottom line is that percent changes/hour due to these various effects can be translated into decay constants which in turn are used for the calculation of power as a function of time. The best form for Equations

IV-2 and IV-3 have yet to be determined and is an area requiring further research. The same is true of determining the necessary components for the two aggregated percent change/hour values, P_{BA} and P_{AA}. For the purposes of this thesis, it is assumed that this data is available so the corresponding decay constants, LBA and LAA, can be calculated.

c. **Situational Inherent Power (SIP)**

This is the power at time $t > t_P$, predicted at time t_P. For time $t < t_A$, this implies the entity's power is discounted. The equations for SIP, also proposed by Kilmer [Ref. 1:p. 39], are:

$$SIP(t|t_P) = PABIP(t_A|t_P) \times \exp[-D(t_A-t)] \qquad 0 <= t <= t_A$$

(eqn IV-7)

$$SIP(t|t_P) = PABIP(t|t_P) \qquad t >= t_A$$

$$= PABIP(t_A|t_P) \times \exp[-L_{AA}(t-t_P)] \qquad t >= t_A$$

(eqn IV-8)

Where: D = Before Arrival Discount Constant.

$$D = \frac{-\ln 0.05}{t_A - t_O}$$

(eqn IV-9)

Equation IV-7 is based on the assumption that the power of an entity before it has arrived is the entity's arrived power discounted exponentially. D is the exponential discount constant. The equation for D, Equation IV-9, follows from assigning an arbitrarily small fraction of readiness, 0.05 in Equation IV-9, to an entity when, at time t_O, that entity is just entering the opposing entity's area of interest.

During the course of developing the example which follows it became apparent that Equations IV-8 and IV-9 apply only to moving entities. Once the entity is in place and waiting for the approaching enemy, the SIP must be calculated using Equations IV-2 and IV-3 with the stationary entity's t_A set equal to that of the moving entity.

4. General Case Example

At this point, an example will illustrate the procedure for applying the above definitions. The procedure is as follows:

Step 1: Calculate t_A from the entity's distance to the mission location and expected ground speed.

Step 2: Determine BIP (user input).

Step 3: Calculate ABIP from Equation IV-1.

Step 4: Calculate L_{BA} using Equation IV-4 and P_{BA}.

Step 5: Calculate L_{AA} using Equation IV-4 and P_{AA}.

Step 6: Calculate $PABIP(t_A|t_P)$ from Equation IV-2.

Step 7: Calculate D from Equation IV-9 (required only if Equations IV-7 and IV-8 are to be used in Step 8).

Step 8: Calculate SIP from Equations IV-7 and IV-8 or from Equations IV-2 and IV-3 if the entity is in place and waiting for the enemy.

The following example illustrates the use of GVS for making comparisons between Red and Blue combat power. It is not meant to be all-encompassing, but is intended to be a simplified version of how VIC could use GVS. This example is purposely patterned after Kilmer's example [Ref. 1:p. 68-95]. This example is presented from the point of view of a Blue Tank Battalion Commander.

a. Scenario

A Blue Tank Battalion (X1) is defending a specified area against an approaching Red Tank Regiment (Y1). The X1 mission is to prevent Y1 from advancing past the current location of the X1 rear boundary in the next 6 hours.

b. Initial Situation

X1 is at full strength, has a BIP of 1000 SPU, and is in prepared defensive positions waiting for Y1. Y1 is at full strength, has a BIP of 3600 SPU, entered the X1 area of interest at time t = -1, and is moving forward at a constant speed.

c. The Y1 SIP Curve

Step 1: Suppose that Y1 has a distance and expected speed which yields $t_A = 3$ hours.

Step 2: BIP(Y1) = 3600 SPU was given above.

Step 3: Next suppose that intelligence estimates that Y1, at time $t_P = 0$ hours, has a complete basic load, has the mission to attack X1, and that under these conditions Equation IV-1 estimates that the Y1 ABIP is 100% of its BIP:

$$ABIP(t_P) = (1.00) \times 3600 \text{ SPU} = 3600 \text{ SPU}$$

Step 4: Continuing, the Y1 P_{BA} is estimated to equal 3% per hour. From Equation IV-2:

$$L_{BA} = -\ln[1-P_{BA}] = -\ln[1-0.03] = 0.0304592 \text{ (1/Hour)}$$

Step 5: Similarly, suppose the Y1 P_{AA} is estimated to equal 10% per hour. From Equation IV-2:

$$L_{AA} = -\ln[1-P_A] = -\ln[1-0.10] = 0.1053605 \text{ (1/Hour)}$$

Step 6: Substitute $t = t_A = 3$ hours into Equation IV-2 and solve for $PABIP(t_A|t_P)$:

$$\begin{aligned} PABIP(t_A|t_P) &= ABIP(t_P) \times \exp[-L_{BA}(t_A-t_P)] \\ &= (3600 \text{ SPU}) \times \exp[-0.0304592(3-0)] \\ &= 3285 \text{ SPU} \end{aligned}$$

Step 7: From Equation IV-9:

$$D = \frac{-\ln 0.05}{t_A - t_O}$$

$$= \frac{-\ln 0.05}{3 - 0}$$

$$= 0.998577 \text{ (1/Hour)}$$

Step 8: The Y1 SIP curve is then described using Equations IV-7 and IV-8:

$$SIP(t|t_P) = PABIP(t_A|t_P) \times \exp[-D(t_A-t)] \qquad t <= t_A$$
$$= (3285 \text{ SPU}) \times \exp[-0.998577(3-t)] \qquad t <= 3$$

$$SIP(t|t_P) = PABIP(t_A|t_P) \times \exp[-L_A(t-t_P)] \qquad t >= t_A$$
$$= (3285 \text{ SPU}) \times \exp[-0.1053605(t-0)] \qquad t >= 3$$

d. **The X1 SIP Curve**

Step 1: With X1 already in place, t_A becomes the time when the enemy will arrive, so $t_A = 3$.

Step 2: BIP(X1) = 1000 SPU was given above.

Step 3: Next suppose that X1, at time $t_P = 0$, has a complete basic load, has the mission to defend against Y1 at their current location until time t = 6 hours, and that under these conditions Equation IV-1 estimates the X1 ABIP to be 100% of the BIP:

$$ABIP(t_P) = (1.00) \times 1000 \text{ SPU} = 1000 \text{ SPU}.$$

Step 4: Suppose the X1 P_{BA} is estimated to equal 2% per hour. From Equation IV-2:

$$L_{BA} = -\ln[1-P_{BA}] = -\ln[1-0.02] = 0.0202027$$

Step 5: Similarly, suppose the X1 P_{AA} is estimated to equal 8% per hour. From Equation IV-2:

$$L_{AA} = -\ln[1-P_A] = -\ln[1-0.08] = 0.0833816$$

Step 6: Substitute $t = t_A = 3$ hours into Equation IV-2 and solve for $PABIP(t_A|t_P)$:

$$\begin{aligned} PABIP(t_A|t_P) &= ABIP(t_P) \times \exp[-L_{BA}(X1)(t_A-t_P)] \\ &= (1000 \text{ SPU}) \times \exp[-0.0202027(3-0)] \\ &= 941 \text{ SPU} \end{aligned}$$

Step 7: Equation IV-9 is not appropriate since X1 is in place and waiting for Y1.

Step 8: The X1 SIP curve is then described using Equations IV-2 and IV-3:

$$\begin{aligned} SIP(t|t_P) &= ABIP(t_P) \times \exp[-L_{BA}(t-t_P)] && t <= t_A \\ &= (1000 \text{ SPU}) \times \exp[-L_{BA}(t-t_P)] && t <= 3 \end{aligned}$$

$$\begin{aligned} SIP(t|t_P) &= PABIP(t_A|t_P) \times \exp[-L_A(t-t_A)] && t >= t_A \\ &= (941 \text{ SPU}) \times \exp[-L_A(t-t_A)] && t >= 3 \end{aligned}$$

Historically, the defending side has a significant advantage over the attacker. This advantage is generally considered to be on the order of three to one against the attackers. For this reason, the SIP(X1) is multiplied by three. The resulting sector SIP curves are given in Figure IV-1.

B. DECISION MAKING WITH GVS

1. Decision Timing

With GVS, answering the question of when to order the execution of a course of action is accomplished via the reiterative application of a "course of action evaluation process". The easiest way to describe this process, and how it determines when to make a decision, is from a "GVS commander's" point of view. This is presented first for the simplest case of all GVS decision methods, introduced previously in Section II.C. The differences between the simplest case and the general case, also introduced in Section II.C, are then discussed. Last, the rationale on the mechanics of the timing is explained.

a. Simplest Case

First, consider the N=1 case of the sub-optimal decision method described earlier in Section II.C. In this case, courses of action are evaluated, one at a time, until the first "feasibility restoring course of action" is found and ordered executed (i.e., only the first measure of effectiveness described in Section II.C is used).

The present time is $t_p = 0$ hours. The commander sees in Figure IV-1 (described previously) that his X1 sector is infeasible, the Y1 SIP curve goes above his X1 SIP

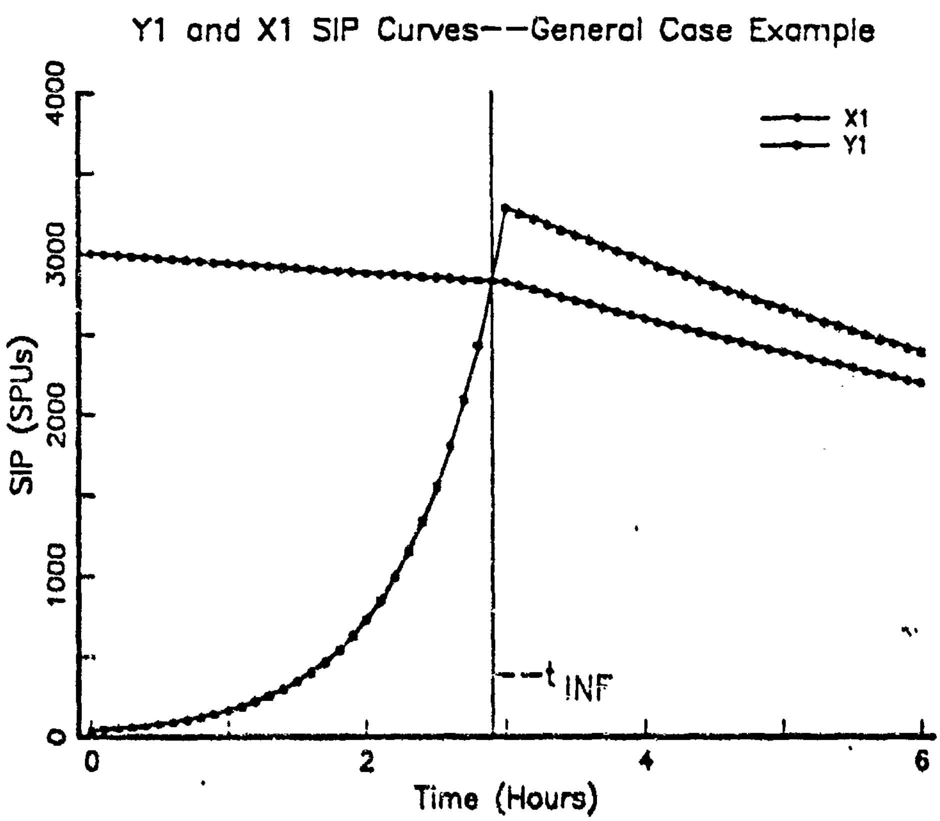

Figure IV-1. SIP Curves--General Case Example

curve before the end of his decision horizon of 6 hours. The commander further sees that his infeasible time (i.e., when the sector goes infeasible) is t_{INF} = 2.9 hours.

Suppose the first available course of action he wants to evaluate is an artillery "prosecution" which has a "notification time" of t_{NT} = 1.5 hours. The notification time is the minimum time between when the commander says "Do it." (the decision time, t_D) and when the subordinate commander can say "We are in place and doing it." (the execution time, t_E).

Subtracting t_{NT} = 1.5 hours from t_{INF} = 2.9 hours, the commander calculates that the decision must be made not later than time t = 1.4 hours. However, the commander has a "decision cycle length" of C = 0.5 hours. This decision cycle length defines the frequency of "decision points", when the commander checks the sector feasibility, evaluates courses of action, and makes decisions.

Between now and time t = 1.4 hours, the only decision points occur at 0, 0.5, and 1.0 hours. Since decisions occur only at decision points, the commander finds the possible execution times by adding t_{INF} to the decision points. This yields possible execution times of t_E = 1.5, 2.0, and 2.5 hours.

The commander then calculates revised sector SIP curves including the artillery prosecution at 2.5 hours. If these "t_E = 2.5 curves" produce feasibility throughout the 6 hour decision horizon, the commander stops and waits until the next decision point at time $t = 0.5$ hours. No decision is required because the "t_E = 2.5 curves" equate to a decision time of $t_D = 1.0$ hours. A decision time not equal to the present time means no decision required.

However, if the "t_E = 2.5 curves" do not produce feasibility, the commander calculates the "t_E = 2.0 curves". If these are feasible, he stops and waits until time $t = 0.5$ hours. No decision is required because the "t_E = 2.0 curves" equate to a decision time of $t_D = 0.5$ hours. Again, a decision time not equal to the present time means no decision required.

However, if the "t_E = 2.0 curves" do not show feasibility, the commander calculates the "t_E = 1.5 curves". If these are feasible, he orders the artillery prosecution course of action executed. A decision was required this time because the t_E = 1.5 curves equate to a decision time of $t_D = 0$ hours. Thus, the only way the artillery prosecution course of action can restore feasibility is for the decision to be made now, because the decision time equals the present time, $t_D = t_P = 0$.

However, if the $t_E = 1.5$ curves do not show feasibility, the commander must reject the artillery prosecution course of action since it failed to produce feasibility at any of it's possible execution times. The commander selects another available course of action and the process starts over. If no available course of action can restore feasibility, the commander requests additional assets from the next higher commander.

b. General Case

Now consider the more general case where N>1 courses of action are evaluated simultaneously. The process is the same as above, except for the following changes. The process described above is applied to N courses of action. The difference in the SIP curves, the second measure of effectiveness described in Section II.C, is then applied to those which met the feasibility restoration measure of effectiveness. The course of action with the greatest difference is the best course of action. If none of the N courses of action can restore feasibility, a second set of N courses of action is selected and the process starts over.

c. Rationale

In the course of action evaluation process described above, starting at the latest execution time and working downward is equivalent to the commander asking "Can I get feasible later?" and "Can I withhold my uncommitted assets for now?". The commander asks these questions because it is better to postpone a decision as long as the sector can be made feasible by a later decision. This is related to the air/land battlefield concept of agility.

Agility is affected in two ways by delaying a course of action to the latest possible moment: (1) a course of action executed at the latest possible moment will minimize the enemy's time to react, thus minimizing enemy agility; (2) if the situation changes, a greater need elsewhere may develop for the entity whose commitment was delayed to the latest possible moment, thus maximizing friendly agility.

2. Determining the Best Course of Action

To implement the course of action evaluation process described above, a method is needed for recalculating the sector SIP curves when a course of action commits more friendly power to the sector.

a. Fletcher's Method [Ref. 2]

When more than one entity was committed to a sector, Fletcher added the SIP curves of all the entities in the sector. In this way, he was able to determine the best course of action for tactical planning (i.e., which friendly entity engages which enemy entity). Fletcher's artillery assets were treated like any other entity; artillery SIP was simply added to the sector total.

Unfortunately, for artillery munition selection, this approach is too aggregated. As used by Fletcher, the SIP curve for an artillery entity is independent of the munition category being used. The entire munition selection process is implicitly rolled into the SIP. In order to make munition selections using GVS, a more explicit method is needed.

One possible method is to use Fletcher's basic method, but have different BIPs for the same artillery entity, one for each munition category. Setting aside the problem of determining these different BIPs, this method is not an improvement; the munition with the greatest BIP would simply be the munition of choice. In fact, this would make the entire munition selection process a simple ranking by BIP, which is essentially the current method used in VIC. Another reason this method is unsatisfactory is that simply having different BIPs does not take advantage of GVS's ability to separately model attrition effects and delay effects.

b. The Parametric GVS Method

Consider the "real world" battlefield VIC is trying to model. Focus on an artillery entity prosecuting a single fire mission against a specific target entity, for a specific benefitting entity. When the fire mission began, Fletcher's method would add the power of the entire artillery entity to the benefitting entity and then subtract it away a few moments later at the end of the fire mission.

This is unrealistic. The effects of that fire mission do not just disappear after completion. What really happens is the fire mission changes many of the target entity attributes. In GVS, these entity attributes are represented by the "parameters" that were used to calculate the target entity's and, to a lessor extent, the benefitting entity's SIP curves. Thus, one way to model a particular munition category's unique "munition effects" would be to adjust the GVS parameters of every entity in the sector accordingly.

The next section will consider the relationships between the various categories of munitions and the GVS parameters.

C. MUNITION EFFECTS AND GVS PARAMETERS

Recall from the working definitions and discussion in Section III that VIC explicitly models the effects of six categories of artillery munitions: HE, non-persistent chemical, persistent chemical, FASCAM, smoke, and jammer. Each of those is a separate category because of their unique tactical effects. The rest of this thesis will focus on only four of these: HE, persistent chemical, FASCAM, and smoke.

Non-persistent chemical is not considered because it is a special case of a persistent chemical with a short duration of effectiveness. As such, modeling non-persistent chemical is similar to modeling a persistent chemical whose effects can be "turned off" after a certain amount of time has passed. Jammer munitions are excluded because, as in the Special Munition Decision Table developed in Section III, little information is available on the principles of their tactical employment.

The remaining four categories have four major tactical effects. TABLE IV-1 shows the categories and their respective effects. Next, it is necessary to explicitly identify the GVS parameters. Consider first the target entity. The following discussion identifies which of these parameters are affected by each of the four munition effects and qualitatively how they change. TABLE IV-2 presents the same information in a condensed format.

TABLE IV-1. ARTILLERY MUNITIONS CATEGORIES AND EFFECTS

	Immediate Attrition	Delayed Attrition	Degradation	Delay
HE	X			
Chemical	X	X	X	X
FASCAM		X		X
Smoke			X	

Immediate Attrition:

t_A--will increase due to reactions to fire.

ABIP--will decrease due to losses.

Delayed Attrition:

P_{BA}--will increase due to increased hazards.

P_{AA}--will increase due to increased hazards and because in combat less attention will be paid to those hazards.

Degradation:

t_A--will increase because movement will slow to react to, and compensate for, the increased hazards.

ABIP--will decrease because the entity will be less efficient.

P_{BA}--will increase because individual skills are degraded.

P_{AA}--will increase because individual skills are degraded and because combat is more demanding of operator skills.

Delay:

t_A--will increase because the entity will have to slow significantly, perhaps even stop, to deal with the increased hazard.

Now consider the benefitting entity. Only two of its GVS parameters, t_A and P_A, can be expected to change. In the case where the benefitting entity is stationary before reaching the target entity, the benefitting entity uses the target entity's t_A and Equations IV-2 and IV-3 (rather than IV-8 and IV-9) to determine its SIP curve. Thus, if the target entity's t_A changes, the benefitting entity's t_A

TABLE IV-2. QUALITATIVE MUNITION EFFECTS ON GVS PARAMETERS

	Immediate Attrition	Delayed Attrition	Degradation	Delay
Benefitting Entity:				
P_A	-	-	-	-
Targeted Entity:				
t_A	+	NC	+	+
ABIP	-	NC	-	NC
P_{BA}	NC	+	+	NC
P_A	NC	+	+	NC
t_P	NC	NC	NC	NC
t_O	NC	NC	NC	NC

KEY: "+" Parameter increased.
"-" Parameter decreased.
"NC" No change in parameter.

changes also. In all cases, the benefitting entity's P_{AA} will decrease because the target entity's ability to attrite the benefitting entity will decrease.

TABLE IV-3 combines the information in TABLEs III-1 and III-2, establishing the qualitative relationship between the munitions categories and the GVS parameters. TABLE IV-3 was derived by combining the columns of TABLE IV-2 as appropriate for each munition according to TABLE IV-1. The multiple +/- signs indicate the number of ways in which that munition category affects that GVS parameter; it does not reflect any relationships between the munition categories.

TABLE IV-3. QUALITATIVE MUNITIONS CATEGORIES AND VIC PARAMETERS RELATIONSHIPS

	HE	Chemical	FASCAM	Smoke
Benefitting Entity:				
P_A	-	----	---	-
Targeted Entity:				
t_A	+	+++	+++	+
ABIP	-	--	--	-
P_{BA}	NC	++	+	+
P_A	NC	++	NC	+
t_P	NC	NC	NC	NC
t_O	NC	NC	NC	NC

KEY: "+" Parameter increased.
"-" Parameter decreased.
"NC" No change in parameter.

TABLE IV-3 establishes a new set of relationships that the VIC model user must input. With that input, GVS can be used to make munitions decisions in a manner similar to the previous General Case Example. The next section illustrates this process.

D. EXAMPLE OF MUNITION DECISION MAKING WITH GVS

The following example illustrates the use of GVS for making artillery munition decisions. As a continuation of the previous example, this is not meant to be all-encompassing, but is intended to be a simplified version of how VIC could use GVS to model artillery munition decisions.

TABLE IV-3 listed the qualitative relationships between the munition categories and the GVS parameters. To proceed with the example, quantitative relationships are required. TABLE IV-4 replaces TABLE IV-3 with quantitative relationships for this example.

Also assumed for this example is the duration of the effects given a single artillery prosecution. With a 6 hour decision horizon, all effects were assumed to be permanent once the artillery prosecution had been made.

The information required to answer the munition category decision is now available. Recall the course of action evaluation process described earlier and suppose the courses of action now available to the X1 commander are artillery delivered HE, persistent chemical, FASCAM, or smoke. In applying the evaluation process, the X2 commander calculates the sector SIP curves for each course of action. These are presented in Figure IV-2.

Checking first for feasibility eliminates all but the HE and Chemical munition categories. Looking at the difference in the Red and Blue SIP curves at the end of the decision horizon at time t = 6 hours indicates that the munition of choice is chemical.

TABLE IV-4. EXAMPLE PERCENT CHANGES TO GVS PARAMETERS DUE TO A SINGLE ARTILLERY PROSECUTION

	HE	Chemical	FASCAM	Smoke
Benefitting Entity:				
P_A	-15	-20	-5	-10
Targeted Entity:				
t_A	+10	+25	+35	+15
ABIP	-15	-10	-5	NC
P_{BA}	NC	+30	+30	+15
P_A	NC	+35	NC	+20
t_P	NC	NC	NC	NC
t_O	NC	NC	NC	NC

The decision to use chemical munitions for this example concludes the development and demonstration of the Parametric GVS Method and represents the accomplishment of the second goal of this thesis.

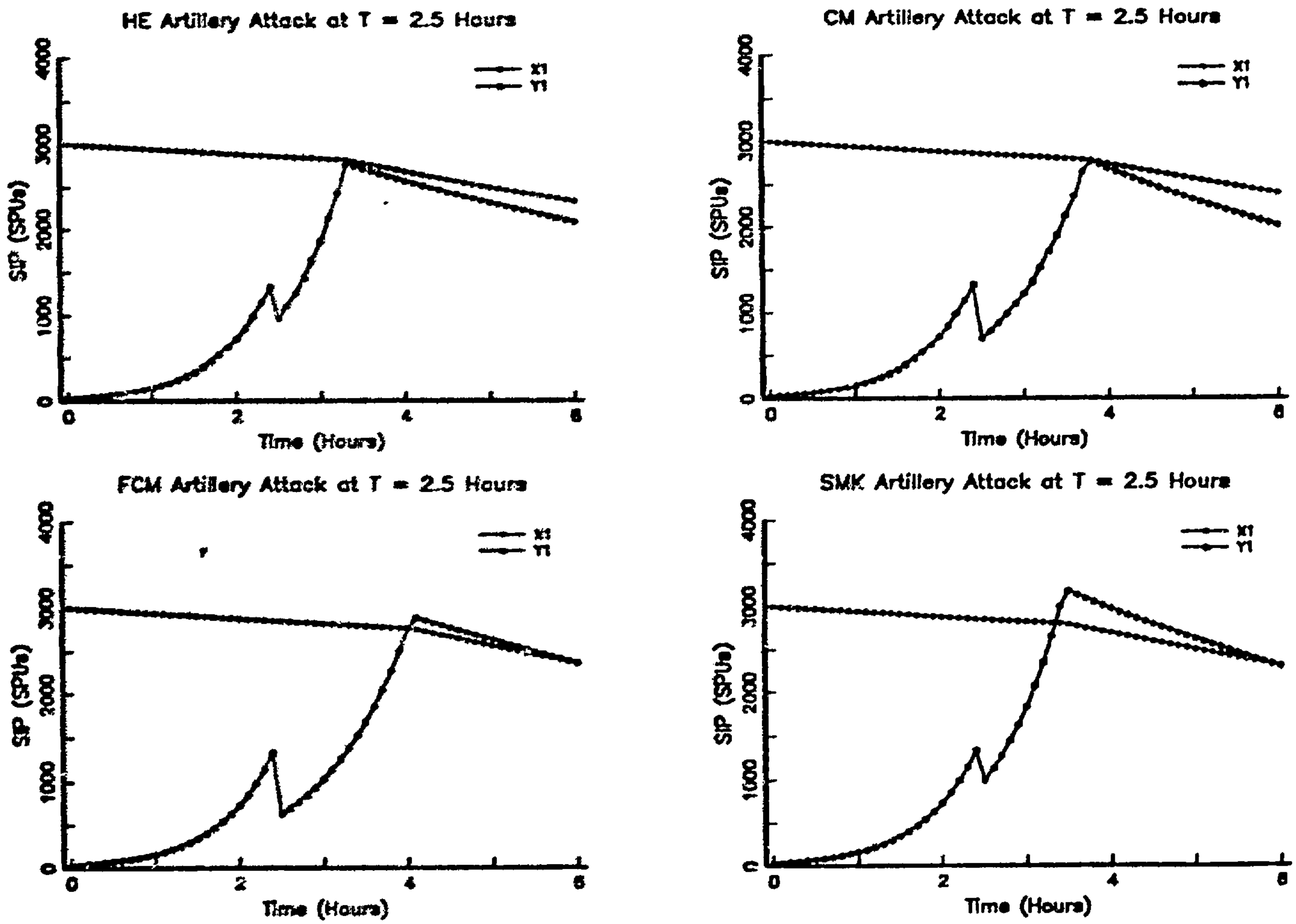

Figure IV-2. Special Munition SIP Curves

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis has accomplished three goals. These were (1) an improvement to the Vector-In-Commander Combat Simulation, (2) the demonstration of GVS's usefulness with respect to artillery munition selection, and (3) documenting the theories behind the VIC and GVS decision methodologies.

1. Special Munition Decision Table

The Special Munition Decision Table and associated changes presented in Section III represent an immediately usable improvement for the explicit representation of the artillery munition selection process in the Vector-In-Commander Combat Simulation.

2. Parametric GVS Methodology

The Parametric Generalized Value System Methodology developed in Section IV has been shown to be capable of explicitly modeling artillery munitions decisions with all the advantages of the Generalized Value System's future state decision making capabilities. Further, this methodology demonstrates that the Generalized Value System method can be applied to a higher resolution of decision modeling than previously attempted.

3. VIC and GVS Decision Methodology Theory

Appendix A is a stand alone document which identifies, explains, and compares the theoretical "underpinnings" of the Vector-In-Commander (VIC) decision methodology and the Generalized Value System (GVS) decision methodology.

4. Decision Table Versus GVS

The Parametric GVS Method has two major advantages over the Special Munition Decision Table. One advantage is that the Parametric GVS Method is grounded in data. As mentioned earlier, Crawford [Ref. 6] has already gathered and analyzed data concerning power as a function of personnel, ammunition, vehicles, and POL. In contrast, the Special Munition Decision Table must rely on tactical decision rules. Another, perhaps equally important, advantage is the way GVS makes decisions, by predicting the future. In this way, GVS is attempting to model the real world--the always predicting human brain.

B. RECOMMENDATIONS

As just mentioned, the weakness of the Special Munition Decision Table lies in the tactical decision rules used in the table's development. Acceptance of these rules requires validation on two levels. First, the rules should be reviewed by the U.S. Army Artillery School for their doctrinal content. Second, a VIC analyst/programer should review and test the rules for their ability to interact with the VIC model and for the results they produce when used in the model.

The Parametric GVS Method has a similar weakness. The data concerning a munition category's effects on the GVS parameters is analogous to the Special Munition Decision Table's tactical decision rules. The challenge here is to extract the parameter changes from data already available and/or get the data by conducting simulations; computer simulations if possible, war game simulations if necessary.

APPENDIX A

VIC AND GVS DECISION METHODOLOGY THEORY

This appendix is a stand alone document whose purpose is to identify, explain, and contrast the theoretical "underpinnings" of the Vector-In-Commander (VIC) decision methodology and the Generalized Value System (GVS) decision methodology. This effort was deemed particularly necessary since none of the VIC references nor any of the GVS references undertook this task. Four areas of theory will be considered: Game Theory, Multiattribute Decision Theory, Forcasting Theory, and Utility Theory. To maintain the stand alone nature of this appendix, a review of the basic elements of each theory is presented followed by the explicit identification of their application to VIC and GVS. The background section is included from the main body of the thesis for the same reason.

A. BACKGROUND

1. VIC Background

VIC uses a decision table structure for making decisions internally as a scenario proceeds. This structure is a set of conditions and a set of actions built into a complex structure of "if...then..." statements in the form of a table. For example, consider VIC Decision Table D1 [REF. 5] presented in Figure A-1.

A Red regiment on the forward line of troops with an inactive status will cause Table D1 to be accessed. The table conditions are then examined columnwise until a column is found that matches the current situation. The actions in that column are then executed and the table is exited.

```
D1       RED FLOT RGT INACTIVE 3 2 4

C19      Y    Y    //**IS THIS A 1ST ECH UNIT?
C46      Y    -    //**HAS SYNCH TIME AT LAST LOC BEEN MET?
C651     .0   -    //**HAVE WE SIMULATED >... DAYS?

A14      X    -    //**ATTACK
A1005    X    -    //**ACCESS DECISION TABLE 5
```

Figure A-1. VIC Decision Table D1 [REF. 5]

Specifically above, if the entity is a first echelon unit and the entity meets the synchronization time at its last location and the model has simulated greater than 0.0 days, then the regiment's status will be changed to attack (i.e., ordered to attack) and Decision Table D5 RED FLOT RGT ATTACK will be accessed.

An exception to the usual column-match and exit routine is when action A999 CONTINUE SCAN is one of the actions in the matched column. In that case, the columnwise search will continue with possibly more actions executed if another match is made. If no column is matched, the table is exited with no new actions initiated.

The version of VIC used for this thesis had 92 decision tables constructed from 238 conditions and 143 actions. Unfortunately for anyone attempting to "read" these tables, the comment lines included in the above example are not present in the standard table listing, but were in separate condition and action listings. This gives the task of learning to read VIC decision tables a very long and tedious learning curve.

2. GVS Background

a. General

The GVS methodology basically consists of a way of calculating the combined "value" of all the entities in a sector for each side. This value is a function of the availability of different type entities in the sector, those entity's capabilities, their assigned missions, and their proximity in time to performing those assigned missions. The sector situation is represented by a pair of "value curves"--a Blue value-vs-time curve and a Red value-vs-time curve.

The value curves described above extend from the current time out to the end of the commander's "decision horizon", defined in hours according to the level of command. Within this thesis, a combat sector is defined as "infeasible" if the commander's value curve falls below the enemy's value curve any time during the decision horizon.

The commander's goal is to always be feasible. Once infeasible, the commander must compare the courses of action available to him and decide which to implement.

In the optimal GVS decision method, the commander would calculate a revised pair of value curves for each available course of action. Then, using one or more measures of effectiveness, one course of action is selected for implementation. If no available course of action meets the selected measure(s) of effectiveness, a request for additional resources is made to the next level of command and the process continues at that level.

Because calculating a pair of value curves for every available course of action is usually computationally prohibitive, a sub-optimal decision method is to compute a pair of value curves for N courses of action and select the "best" by applying the selected measure(s) of effectiveness.

This appendix uses the same two measures of effectiveness used within the main body of the thesis. The first measure of effectiveness is feasibility restoration. That is, if by varying the time of execution, a course of action cannot restore feasibility, that course of action is eliminated. The second measure of effectiveness is the difference between the two value curves at the end of the decision horizon. The course of action with the greatest difference in value at the end of the decision horizon is the optimum or best course of action.

This appendix, also like the thesis main body, assumes that the value of an entity is equal to its power. Under this assumption, the word "power" is substituted for the word "value" in the above general description. This same assumption is made for the rest of this appendix.

b. GVS Equations

The following equations are those proposed by Kilmer [Ref. 1] as a first order approximation for the Situational Inherent Power (SIP) and were used in the main body of this thesis. The equations are presented only so their form can be analyzed for theoretical content; their derivations and rationale can be found in the thesis main body or in Kilmer's thesis [Ref. 1]. The equation numbers are those used in the thesis main body. Equation IV-3 is redundant to Equation IV-8 and is not included. The equations are followed by definitions of the variable names.

$$ABIP(t) = f(BIP, \underline{S}(t))$$

(eqn IV-1)

$$PABIP(t_A | t_P) = ABIP(t_P) \times \exp[-L_{BA}(t_A - t_P)]$$

(eqn IV-2 at $t = t_A$)

$$L_{AA} = -\ln[1 - P_{AA}]$$

(eqn IV-4 with $L = L_{AA}$ and $P = P_{AA}$)

$$L_{BA} = -\ln[1-P_{BA}]$$

(eqn IV-4 with $L = L_{BA}$ and $P = P_{BA}$)

$$P_{BA} = - P_{BASU} + P_{BASR} - P_{BANPA} - P_{BAIPA} + P_{BAPR}$$

(eqn IV-5)

$$P_{AA} = - P_{AASU} + P_{AASR} - P_{AANPA} - P_{AAIPA} + P_{AAPR}$$

(eqn IV-6)

$$SIP(t|t_P) = PABIP(t_A|t_P) \times \exp[-D(t_A-t)] \qquad 0 <= t <= t_A$$

(eqn IV-7)

$$SIP(t|t_P) = PABIP(t_A|t_P) \times \exp[-L_{AA}(t-t_P)] \qquad t >= t_A$$

(eqn IV-8)

$$D = \frac{-\ln 0.05}{t_A - t_O}$$

(eqn IV-9)

t = time (Hr)
t_O = time of Entry into Enemy Area of Interest (Hr)
t_P = time of Prediction or Present Time (Hr)
t_A = time of Arrival [at mission start location] (Hr)
(Hr = Hours)

ABIP = Adjusted Basic Inherent Power (SPU)
BIP = Basic Inherent Power (SPU)
PABIP = Predicted ABIP (SPU)
SIP = Situational Inherent Power (SPU)
(SPU = Standard Power Units)

$\underline{S}$ = State of Entity (Multiattribute Vector)

L_{BA} = Loss Rate Decay Constant Before Arrival (1/Hr)
L_{AA} = Loss Rate Decay Constant After Arrival (1/Hr)
D = Discount Constant (1/Hr)

P_{BA} = Percent Change/Hour Before Arrival
P_{AA} = Percent Change/Hour After Arrival

P_{BASU} = Before Arrival Supplies Usage
P_{BASR} = Before Arrival Supplies Replenishment
P_{BANPA} = Before Arrival Noncombat Personnel Attrition
P_{BAIPA} = Before Arrival Indirect Fire Personnel Attrition
P_{BAPR} = Before Arrival Personnel Replenishment

P_{AASU} = After Arrival Supplies Usage
P_{AASR} = After Arrival Supplies Replenishment
P_{AACPA} = After Arrival Combat Personnel Attrition
P_{AAIPA} = After Arrival Indirect Fire Personnel Attrition
P_{AAPR} = After Arrival Personnel Replenishment
(All "P" variables have units of Fraction/Hr)

D = Discount Constant (1/Hr)

Within the above equations, the GVS "parameters" identified in the thesis main body are the entity attributes t_O, t_P, t_A, ABIP, P_{BA}, and P_{AA}. That is, given data for these entity attributes, the entity's "SIP curve" can be calculated. Figure A-2 is an example set of SIP curves calculated and presented in the main body of this thesis.

B. GAME THEORY

1. Essential Elements of Game Theory

The foll wing game theory definitions and descriptions are abridged from a more detailed treatment found in Decision Analysis by Gregory [Ref. 7].

a. General

The classic scenario of a simple game is the situation in which there are two "players" (Player I and Player II), one of which can be "Nature" itself. Player I has a set of available alternatives (a_i) from which one

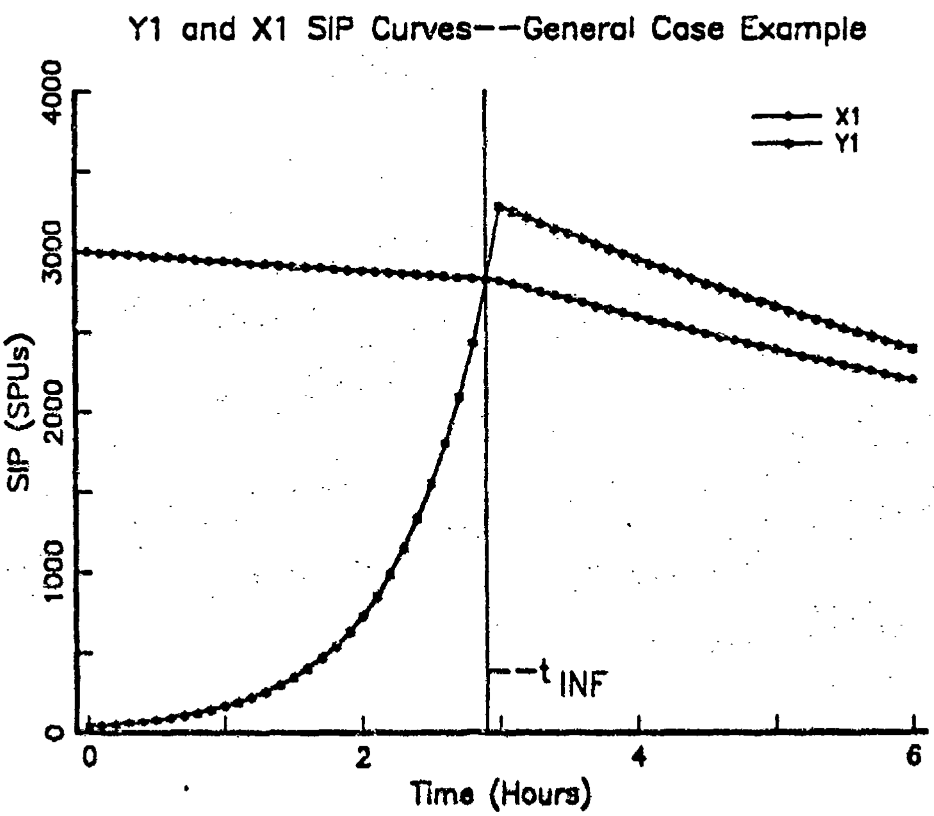

Figure A-2. SIP Curves--General Case Example alternative must be chosen. Player II, likewise, has his own set of available alternatives (b_j). For each pairing of a Player I alternative and a Player II alternative, there is a payoff (r_{ij}) associated. All alternatives and their respective payoffs are known to both players. TABLE A-1 illustrates the standard "payoff matrix" for the simple case of each player having two alternatives.

TABLE A-1. SIMPLE TWO-PERSON GAME

		Player II Alternatives:	
		b_1	b_2
Player I Alternatives:	a_1	r_{11}	r_{12}
	a_2	r_{12}	r_{22}

There are two versions of this type of two person game: the Two-Person Zero-Sum Game and the Two-Person Non-Zero-Sum Game. The versions differ primarily on alternative costs and on the type of prize being competed over. These primary differences lead to secondary differences on the number of payoff matrices required, how the payoff values are defined, and on the extent that cooperation is a possible strategy. These differences will be discussed and identified as each version is presented. In addition, a special case of the Two-Person Non-Zero-Sum Game, the Person vs Nature Game, is presented.

b. The Two-Person Zero-Sum Game

For the zero-sum version, there is an implicit assumption that all alternatives for both players have a zero cost. Also implied is that the players are competing to completely divide some finite prize (i.e., one player's loss is always the other player's gain). Because of the prize's finite nature, only one payoff matrix is needed. Each entry of this payoff matrix is the prize amount to be gained by Player I, the balance going to Player II. Because the prize is completely divided, there is never any rational reason for the players to cooperate. TABLE A-2 illustrates a zero-sum version in which the total prize is 12 units.

TABLE A-2. SIMPLE TWO-PERSON ZERO-SUM GAME [Ref. 7:p. 57]

		Player II Alternatives:	
		b_1	b_2
Player I Alternatives:	a_1	6	4
	a_2	8	6

There are two strategies applicable to a two-person game, "pure strategy" and "mixed strategy". The pure strategy is actually a special case of the mixed strategy.

The pure strategy is quickly illustrated by again looking at TABLE A-2. From Player I's point of view, alternative a_2 "dominates" a_1. To dominate means that a_2 gives a higher payoff than a_1 for all of Player II's alternatives. Likewise, from Player II's point of view, b_1 dominates b_2. This leads to Player I always using a_2 and Player II always using b_1, hence this pure strategy leads to a "saddle point" at (a_2, b_1) and results in 8 units going to Player I and 4 units going to Player II. Any player who departs from the saddle point will be worse off.

By contrast, there exist situations in which there are no dominant alternatives. These situations require a mixed strategy. Such a situation is presented in TABLE A-3.

TABLE A-3. TWO-PERSON ZERO-SUM MIXED STRATEGY SITUATION [Ref. 7:p. 58]

		Player II Alternatives:	
		b_1	b_2
Player I Alternatives:	a_1	12	4
	a_2	8	12

A mixed strategy is applied by Player I deciding to use a_1 with probability p and a_2 with probability 1-p. Similarly, Player II decides to use b_1 with probability q and b_2 with probability 1-q. These probability distributions over each player's actions produces the joint probability distribution described in TABLE A-4.

As a function of p and q, the joint probability distribution produces the expected payoff surface. This

TABLE A-4. MIXED STRATEGY JOINT DISTRIBUTION
[Ref. 7:p. 61]

Player I Alternative	a1	a1	a2	a2
Player II Alternative	b1	b2	b1	b2
Probability	pq	p(1-q)	(1-p)q	(1-p)(1-q)
Payoff	12	4	8	12

three dimensional surface can be shown (graphically or using calculus) to have a saddle point at (p=1/3, q=2/3). As with the pure strategy saddle point, the expected payoff will decrease for any player who departs from the saddle point.

In general, any two-person game can be solved by determining a probability distribution on the alternatives based on expected payoffs. The uniqueness of this method is that it does not help one player to know the other is using this method. Further, any player who does not use this method is placing himself at a disadvantage if his opponent is.

c. The Two-Person Non-Zero-Sum Game

The non-zero-sum version differs from the zero-sum game in that there is an implicit assumption that each alternative has a cost associated with it. These costs are reflected by a reduction in the relevant payoffs. The non-zero-sum version further differs in that the players are competing for a prize whose characteristics prohibit it from being divided between the two (i.e., one player's loss is NOT necessarily the other player's gain).

Because one player's loss is not the other player's gain, one matrix cannot describe both player's payoffs. Each player must have his own payoff matrix, the entries of which are the prize amount to be gained by that player. Also because of the prize's nature and because alternative costs may be significant, there are situations in which cooperation could be advantageous for both players. TABLEs A-5 and A-6 illustrate such a situation.

TABLE A-5. TWO-PERSON NON-ZERO-SUM GAME
PLAYER 1 PAYOFF MATRIX

		Player II Alternatives:	
		b_1	b_2
Player I Alternatives:	a_1	4	7
	a_2	2	5

TABLE A-6. TWO-PERSON NON-ZERO-SUM GAME
PLAYER II PAYOFF MATRIX

		Player I Alternatives:	
		a_1	a_2
Player II Alternatives:	b_1	8	11
	b_2	5	9

The pure and mixed strategies discussed for the zero-sum game are also applicable to the non-zero-sum game, except for the cooperation possibility. It can be seen above that a_1 dominates a_2 and b_1 dominates b_2. Thus, the saddle point is at (a_1, b_1) and results in 4 units going to

Player I and 8 units going to Player II. However, if the two players had cooperated by agreeing to choose a_2 and b_2, Player I would have received 5 units and Player II would have received 9 units.

d. The Person vs Nature Game

As stated previously, this game is a special case of the two-person non-zero-sum game. Nature's quality of "indifference" implies two simplifications. First, Nature is assumed to move randomly among "states" rather than choosing alternatives. This introduces the concept of decision making under conditions of uncertainty. Second, Nature's payoff matrix is assumed to be a matrix of all zeros. These simplifications also change the strategy for this type of game. First, Nature's state probability distribution must be estimated. Second, the person chooses the alternative with the greatest expected payoff.

This is demonstrated using the data in TABLE A-7. The expected payoffs are: for a_1, $0.4(4) + 0.6(11) = 8.2$; and for a_2, $0.4(5) + 0.6(9) = 7.4$. Thus, in this example, the person should always chose a_1.

This completes the Game Theory review. There are many texts, including Gregory [Ref 6] and Moskowitz [Ref. 7] used for this appendix, available on the subject should the reader require a more complete treatment of the

TABLE A-7. PERSON VS NATURE GAME

		Nature's States: s_1	s_2
State Probability:		0.4	0.6
Person's Alternatives:	a_1	4	11
	a_2	5	9

subject. With this review, it is now possible to discuss Game Theory content in VIC and GVS.

2. Game Theory in VIC

As presented, Game Theory included four elements--players, alternatives, payoffs, and strategy. The presence and form of each within VIC is as follows:

Players--the obvious choice for VIC's players are the implied Blue Force and Red Force commanders. Of course, implicitly this includes all the constraints of each side's National Command Authority and Policies.

Alternatives--the sets of Blue and Red alternatives are not quite so obvious. These sets are not obvious because they are infinite. While, at any given time, it is true that both commanders have a finite number of units available to them, these units can be sent anywhere, now or at anytime in the future, to do anything. Thus, position, time, and mission possibilities cause the alternative sets to be infinite. VIC models these infinite alternative sets using 143 actions. Before judging the adequacy of this number too harshly, recall that actions can be implemented in combinations.

Payoffs--VIC has no explicit payoffs. When the conditions are matched in a decision table column, the actions in that column are executed. No comparisons are made, so there is no use for payoff values. VIC's decision strategy, discussed next, explains this lack and its implications.

Strategy--in this area, VIC makes some significant simplifying assumptions. A complete player vs player payoff matrix for VIC would have an infinite set of alternatives for each player. VIC simplifies this by converting the player vs player game (i.e., Blue vs Red), into a player vs Nature game. This removes the enemy alternatives from the game and introduces Nature's states.

Nature, in this case, is the battlefield situation, including both Blue and Red forces. Unfortunately, the state set is still infinite and a probability distribution is now needed for Nature's states. VIC neatly sidesteps both these problems. The state set is limited to the current battlefield situation as definable by combinations of the 238 conditions used in VIC. Thus, this current situation or "real time" decision making limits the state space to exactly one state. This is equivalent to assuming away the uncertainty of nature.

Once the current situation is matched in a VIC decision table, the actions in that column are executed. This implies that some payoff measure was used to determine which actions are best for the matched situation. Within the VIC documentation, two allusions to "tactical decision rules" [Ref. 4:pp. 3,5] were the only references found which might be related to such a payoff measure. Unfortunately, no definition or listing of these "tactical decision rules" was found during the course of this thesis. It is highly probable that these rules are the model builders' attempt to translate doctrine into the VIC model.

3. Game Theory in GVS

The presence and form of the four elements of Game Theory within GVS are as follows:

Players--basically no different than VIC; these are the Blue and Red commanders. A possible significant advantage for GVS is its explicit representation of decision making at various levels of command and the interactions between those levels.

Alternatives--the infinite nature of the alternative sets is the same in GVS as it was in VIC; the way they are handled is not. This is discussed in the strategy section.

Payoffs--GVS has two payoff measures, the measures of effectiveness discussed in A.2.a. For the optimal strategy of comparing all alternatives simultaneously, both measures of effectiveness are used. If more than one alternative is feasible (i.e., first measure of effectiveness), the alternative with the greatest difference between the SIP curves (i.e., second measure of effectiveness) is selected.

The sub-optimal decision strategy compares N alternatives. Except for one case, this strategy also requires both the feasibility measure of effectiveness and the SIP curve difference measure of effectiveness. Only simplest case of the sub-optimal strategy, when N=1, does not require the SIP curve difference measure of effectiveness, since the first feasible alternative is implemented.

Strategy--Game Theory as illustrated so far has dealt with only one measure of payoff. In a decision situation, the desire to consider more than one measure of payoff forces the commander into the realm of Multiattribute Decision Theory. This aspect will be discussed in Section C. For the purposes of Game Theory, the following discussion illustrates that the GVS decision, though Multiattribute in nature, is still using expected values to make the decision.

Both the feasibility measure of effectiveness and the SIP curve difference measure of effectiveness are determined by the SIP curves presented in A.2.b, which are in turn determined by the entity's attribute data supplied by the user. Presumably that data represents average entities. Thus, the resulting measures of effectiveness are the average (i.e., expected) measures of effectiveness and the strategy being used is to select the maximum expected measure of effectiveness alternative. The exception to this is the simplest case of the sub-optimal strategy, when N=1 and one alternative is checked at a time until a feasibility restoring alternative is found. In this case, the strategy being used is "expected restoration of feasibility".

C. MULTIATTRIBUTE DECISION THEORY

1. General

The following definitions and descriptions are abridged from a more detailed treatment found in Operation Research Techniques for Management by Moskowitz and Wright [Ref. 8].

In general, during applications of simple Game Theory, decisions are based on one payoff. However, the results of decisions cannot always be narrowed down to one payoff. This was pointed out in the discussion on GVS Game strategy. In actual practice, decision results can be measured by many different, and often conflicting, payoffs. In Multiattribute Decision Theory these payoffs are called attributes. In GVS discussions these have been called "measures of effectiveness". Multiattribute decision making is the process of using more than one measure of effectiveness to make a decision.

A multiattribute decision situation is composed of three elements. First, the situation must have an overall purpose. Secondly, there must be more than one alternative available, all of which can fulfill the overall purpose. Finally, an alternative's ability to achieve this overall purpose must be describable by more than one attribute.

Given a situation as described above, two intermediate steps may be required before decision models can be considered. First, it may be necessary to "decompose" the attributes until they are a measurable and "sufficiently rich and meaningful set of descriptors to capture the essence of the problem" [Ref. 8:p. 222]. Secondly, it is necessary to get the attribute data for each alternative. TABLE A-8 is a procurement example of the necessary attribute data.

Given the above attribute data, decision making becomes a matter of processing the data in one of many multiattribute decision models.

2. Models

Two models are of interest in this appendix. Both are noncompensatory multiattribute decision models. Noncompensatory means that "tradeoffs" between attributes

TABLE A-8. WIDGET ATTRIBUTES

Attributes:	Alternatives: Widget A	Widget B	Widget C
Cost (Millions)	7	8	6
Schedule (Yrs)	2	1	3
Speed (MPH)	70	90	110
Vulnerability	Average	High	Low

are not permitted. All comparisons are performed on an attribute-by-attribute basis. These two models are described below:

a. Disjunctive Satisficing Model

A satisficing model is one which partitions the alternatives into acceptable or unacceptable categories. For a disjunctive satisficing model, a maximum value is defined for each critical attribute. Any alternative whose critical attributes meet or exceed these critical attribute maximums is deemed acceptable. All others are eliminated.

b. Lexicographic Models

A lexicographic model requires that the attributes be given a priority of importance. The alternatives are then sorted by the value of the most important alternative. If the top alternative is tied, then a secondary sort on the second most important attribute is performed. This continues until the top alternative is not tied. This is the alternative of choice.

2. Multiattribute Decision Theory in VIC

During the Game Theory discussion of VIC, it was pointed out that there is no explicit representation of payoffs. This means there is also no explicit use of multiattribute decision methods. However, if the "tactical decision rules" mentioned in the VIC documentation [Ref. 4:pp. 3,5] are the model builders' attempt to translate doctrine into the VIC model, these rules may be roughly analogous to a disjunctive satisficing model. Doctrine represents a minimum level to be attained in those attribute areas deemed critical.

Decision tables implement this process as follows: (1) attributes are deemed critical by their presence or absence as decision table conditions; (2) answers/thresholds in the columns of the decision table specify the minimum acceptable levels of those critical attributes; and (3) the decision table implements an action because it meets or exceeds those minimum critical attribute levels.

For example, consider VIC Decision Table D1 presented previously in Figure A-1. The conditions imply that the critical attributes are whether the unit is first echelon, whether the synchronization time at the last location was met, and whether more than zero days have been simulated. The first column specifies yes, yes, and 0.0 as the respective minimum acceptable levels. The presence of the actions "attack" and "access Decision Table D5" in that column means there exist tactical decision rules that say "Given the above, attack!". Whether or not these tactical decision rules explicitly exist, the decision tables imply their existence.

3. Multiattribute Decision Theory in GVS

GVS uses two multiattribute decision methods. If the optimal decision strategy of comparing all alternatives was possible, the multiattribute decision method would be the combination of a lexicographic model and a disjunctive satisficing model. The simplicity of this is not immediately evident as all the equations and parameters are considered.

However, the equations and parameters are not a part of the decision process; they are the process by which the different payoffs are determined. Once a set of sector SIP curves are calculated for an alternative, the commander first asks whether this alternative will make the sector feasible. If more than one alternative is being evaluated and more than one is feasible, then the commander decides which one is better using the SIP curve difference measure of effectiveness. The commander is using the sector SIP curves to predict future situations. He does not make decisions from these predictions; rather, he generates measures of effectiveness from them and then uses those to make decisions. This future state prediction is discussed later in Section D, Forecasting Theory.

The multiattribute decision process just described is a lexicographic model. This is evident because two measures of effectiveness are used: the feasibility measure of effectiveness and the SIP curve difference measure of effectiveness. The lexicographic model used specifies that the alternatives be rank ordered first using the feasibility payoff measure, then those alternatives still tied for first place are rank ordered using the SIP curve difference measure of effectiveness.

The rank ordering of the feasibility payoff measure described in the lexicographic model is the application of a disjunctive satisficing model. The critical attribute is feasibility or infeasibility. The minimum acceptable level of the payoff measure is feasibility.

In the sub-optimal decision strategy, in which N alternatives are compared, the same combination of a lexicographic model and a disjunctive satisficing model is used, except for one case. That one case is N=1, in which the first feasibility restoring alternative is implemented.

In the case where N=1, the model being used is the truncated application of a disjunctive satisficing model.

Since only one measure of effectiveness, feasibility, is used, no lexicographic model is required. The application of the disjunctive satisficing model is the same as when N>1, except that the process is truncated before all alternatives are divided into acceptable and unacceptable classes. This truncation occurs as soon as the first feasible alternative is found.

D. FORCASTING THEORY

This section differs from the preceding sections because VIC's current time decision does not use forecasting. On the other hand, GVS's use of the terms "time of prediction" and "Predicted ABIP", together with GVS's end product--a set of SIP curves for the commanders decision horizon--certainly do imply forecasting. This section discusses GVS's use of Forcasting Theory.

The definitions and descriptions on forecasting contained in this section are abridged from a more detailed treatment found in Interactive Forecasting by Makridakis and Wheelwright [Ref. 9].

"The central theme of quantitative techniques of forecasting is that the future can be predicted by discovering the patterns of events in the past." [Ref. 9:p. 13] This statement identifies the two elements of Forecast Theory: (1) data collected from the past; and (2) a method to predict the future using that data. Before discussing either of these elements in detail, it is necessary to understand "GVS's past and future" as it differs from GVS's "forecasting past and future".

1. GVS's Forcasting Past and Future

Suppose there exists a version of VIC with GVS decision methodology instead of decision tables. Further, suppose that this version is in the "middle" of simulating a conflict. From the simulated commander's point of view, he has not been storing and analyzing his loss data up to the present time and then using that data to forecast his power in the next battle. Thus, this commander's point of view is a GVS past and future, not a forecast past and future. A larger viewpoint is necessary to see the forecast past and future.

The forecast past and future are separated by the point in time when data collection stops and predictions begin. GVS's forecast past stopped and its future began as soon as the above described model began execution. In contrast, a GVS past and future was defined every time an SIP curve was calculated during the course of the model. With this understanding, the two elements of forecasting, as applies to GVS, can be identified.

2. Data Collection From GVS's Forcasting Past

a. An Ideal Situation

Consider the following ideal data collection situation, in which the level of resolution is at an absolute maximum. Everything on the battlefield is an entity; be it man, "major-end-item" machine, or a spare bolt. Also because this is an ideal situation, "loss data" in the form of "entity type lost" and "time of loss" can be collected. The number of remaining entities as a function of time is the entity loss function.

In this ideal situation, GVS assigns each entity type a specific power. Using the power values for each entity type, the entity loss functions can be transformed into entity "power loss functions", still functions of time. Then, assuming that the sector power is the sum of the individual entities' power, summing the entities' power loss functions yields a sector power loss function.

This sector power loss function is analogous (as are each of the entity loss functions and the entity power loss functions) to the survival function used in reliability studies. The sector starts at a certain power level and the sector power loss function is the amount of power remaining at time, t, from the start of the battle to the end of the battle.

The next ideal step is to gather data from every possible combat scenario. Then, the best sector power loss model for making predictions in future battles is the one which best fits the sector power loss functions from these scenarios. The model chosen will then determine what parameters need to be calculated from the data.

b. A More Realistic Situation

Obviously, gathering such a wealth of data over every possible combat scenario is impossible. Two questions then become operative. First, how much data is required to achieve a reasonable approximation? Secondly, where are these data? The only way to answer the first question is the scientific method--collect data, build a model, test the model, and start over again if the model is not good enough. The second question has three possibilities: (1) analysis of historical data of real wars; (2) analysis of data from real wargames; or (3) analysis of data from simulations.

3. A Model for GVS's Forcasting Future

Equations IV-7 and IV-8 presented in A.2.b represent the GVS sector power loss model proposed in Kilmer's thesis [Ref. 1] and used in the main body of this thesis. The basic form of these equations imply an exponential decay of power as a function of time. For entities not yet in position to begin their assigned missions, the concept of discounting power is added.

As presented in the thesis main body, Equations IV-7 and IV-8, together with their supporting equations also presented in A.2.b, identify the following GVS parameters: the entity attributes t_O, t_P, t_A, ABIP, P_{BA}, and P_{AA}. That is, given data for these entity attributes, the entity's SIP curve can be calculated. The first three parameters are, except for the entity attributes of location and movement rate, scenario determined. The second three require extensive data collection and analysis.

Equation IV-1 presented in A.2.b stated that ABIP is a function of BIP and S. BIPs are subjectively assigned to entities in some consistent manner. They are conceptually similar to "tank entity equivalents". The vector of entity attributes, S, are those attributes which the model monitors. The task of determining a function for ABIP was addressed by Crawford [Ref. 6]. His model determined ABIP as a function of the percent levels of on-hand personnel, vehicles, ammunition, and POL. Crawford's use of a subjective survey of Army officers illustrates that, like BIP, ABIP is also subjective in nature.

The determination of P_{BA} and P_{AA} from real world data has not been addressed at this time. Equations VI-5 and VI-6 presented in A.2.b probably represent the minimum level of complexity required. The ideal situation described in D.2.a represents the unapproachable maximum level of complexity. Somewhere between the two lies a level of complexity that will produce an acceptable approximation; perhaps it can be based on personnel, vehicles, ammunition, and POL as Crawford [Ref. 6] used for ABIP.

E. UTILITY THEORY

1. General

The following definitions and descriptions are abridged from a more detailed treatment found in Operation Research Techniques for Management by Moskowitz and Wright [Ref. 8].

Classical Utility Theory is required when decisions are made under conditions of risk. A variation on classical Utility Theory is when two things are so qualitatively different that they cannot be compared directly (i.e., the better of two is not readily determinable). In both of these situations, the decision maker is required to make subjective evaluations.

The usual example of the risk situation is a lottery. The basic question is something like "How much money would you be willing to pay to engage in (or to avoid) a lottery with a probability P of winning X dollars and a probability 1-P of losing Y dollars?". The quantity being measured by such a question is the subjective amount of risk the decision maker is willing to tolerate.

By asking many such very carefully worded questions, the decision makers "utility function" can be determined. Such a utility function can be used to quantify the utility, or usefulness, of the decision maker's alternatives as a function of their affect on his total assets.

A good example of the comparison situation can be found in combat modeling. The question posed to the commander would be something like "Given a specific tactical situation, how many infantry companies would you be willing give up for one tank company?". The quantity being measure by such a question is the subjective usefulness of an infantry company as compared to a tank company.

Again, by asking many such very carefully worded questions, the "relative" utility of all entity types can be found. The word "relative" is used because there is no absolute scale; a "reference entity" must be defined and all other entities quantitatively compared to that entity. These quantitative comparisons could then be mapped onto a measurement scale. As with the situation with risk, such a measurement scale quantifies the utility, or usefulness, of the entity types to the commander as a function of his current force mix of entities and the given situation. The situation is included because entity usefulness can vary greatly with the situation; for example, tanks are not very useful in swamps nor is straight leg infantry very useful in the open desert.

2. Utility Theory in VIC

As with the payoffs discussed earlier, VIC's use of Utility Theory is implicit, if at all. It has be suggested that VIC's decision tables are based on tactical decision rules, which are in turn based on doctrine. Doctrine, by its very nature, is the subjective expert opinion of how to wage war. That subjective expert opinion will necessarily be making comparisons of the type described in the variation on Utility Theory described above.

3. Utility Theory in GVS

GVS's use of Utility Theory is the same as VIC's; however, GVS's use is explicit. It was mentioned previously that BIPs are subjectively assigned to entities in some consistent manner. This consistent manner is exactly as described above in the variation on Utility Theory. Such an effort would probably make a good thesis topic.

Another area, similar to BIP, which also requires subjective evaluation is the function for ABIP (Equation IV-1). As previously mentioned, Crawford [Ref. 6] used a subjective survey of Army officers to establish ABIP as a function of personnel, vehicles, ammunition, and POL. This effort is another application of the variation on Utility Theory described above. In this case the comparisons being made are between entities which differ only on the on-hand levels of personnel, vehicles, ammunition, and POL.

APPENDIX B

DECISION TABLE EXAMINATION RESULTS

A. NOTES ON FORMAT

--Relevant conditions are listed for each special munition(s) considered by the decision table.

--NONE is used to list conditions where current tables preclude special munitions.

--Each relevant condition's answer/threshold value is in parentheses after the condition.

--Conditions can be either explicit to the table or implied by the table's resulting action(s).

B. RESULTS

1. Table D1

No modifications necessary since this table's only actions always include accessing Table D2 or Table D5, and their modifications will suffice.

2. Table D2

a. Relevant Conditions:

NONE	C74 (Y), C75 (3.), and C203 (5)?
NONE	C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
A55	C403 (Y) or C405 (Y)?
A54	C1 (Y)?

b. Modifications:

- Combine A54 & A55 to A700, "X"s in columns 2 thru 6.

3. Table D3

a. Relevant Conditions:

A54	C1 (Y)?

NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. **Modifications:**

- Change A54 to A700, "X"s in columns 1 thru 3.

4. **Table D4**

a. **Relevant Conditions:**

NONE C74 (Y), C75 (3.), and C203 (5)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
A57 C403 (Y), C404 (Y), or C405 (Y)?

b. **Modifications:**

- Change A57 to A700, "X"s in columns 1 thru 7.

5. **Table D5**

a. **Relevant Conditions:**

NONE C11 (.3)?
C403 (Y) or C405 (Y)?
C406 (Y)?
C414 (Y)?

b. **Modifications:**

- Add A700, "X"s in columns 1 and 3.

6. **Table D7**

a. **Relevant Conditions:**

NONE C74 (Y), C75 (3.), and C203 (5)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
A55 C1 (Y)?
C403 (Y) or C405 (Y)?
C404 (Y)?
C410 (Y)?

b. **Modifications:**

- Change A55 to A700, "X"s in columns 3 thru 8.

7. **Table D7.5**

a. **Relevant Conditions:**

A55 C403 (Y) or C405 (Y)?

A54 C414 (Y)?

b. Modifications:

- Change A54 and A55 to A700, "X"s in columns 1 thru 3.

8. Table D9

a. Relevant Conditions:

NONE C406 (Y), C410 (Y), or C414 (Y)?

b. Modifications:

- Add A700, "X"s in columns 1 thru 4.

9. Table D10

a. Relevant Conditions:

NONE C1 (Y), C403 (Y), or C405 (Y)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Add A700, "X"s in columns 2 thru 4.

10. Table D11

a. Relevant Conditions:

A55 C1 (Y) or C19 (Y)?

b. Modifications:

- Add A700, "X"s in columns 1 and 2.

11. Table D12

a. Relevant Conditions:

A55 C1 (Y) or C402 (Y)?

b. Modifications:

- Change A55 to A700. "X"s in columns 1 thru 4.

12. Table D16

a. Relevant Conditions:

A58 C58 (15)?

b. Modifications:

- Change A58 to A700, with "X" in column 1.

13. Table D17

a. Relevant Conditions:

A57 C19 (Y), C58 (15), and C613 (Y)?

b. Modifications:

- Change A57 to A700, with "X" in column 1.

14. Table D21

a. Relevant Conditions:

A55 C1 (Y) or C402 (Y)?

b. Modifications:

- Change A55 to A700, "X"s in columns 1 thru 4.

15. Table D31

a. Relevant Conditions:

A55 C402 (Y)?

b. Modifications:

- Change A55 to A700, "X"s in columns 1 thru 4.

16. Table D42

a. Relevant Conditions:

A55 C403 (Y) or C405 (Y)?
A54 C414 (Y)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Change A54 and A55 to A700, "X"s in columns 1 thru 4.

17. Table D43

a. Relevant Conditions:

A54 C1 (Y)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Change A54 to A700, "X"s in columns 1 thru 5.

18. Table D44

a. Relevant Conditions:

A57 C403 (Y), C404 (Y), or C405?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Change A57 to A700, "X"s in columns 1 thru 5.

19. Table D45

a. Relevant Conditions:

NONE C1 (Y), C403 (Y), C405 (Y), or C414 (Y)?

b. Modifications:

- Add A700, "X"s in columns 2 and 3.

20. Table D46

a. Relevant Conditions:

NONE C1 (Y), C403 (Y), or C405 (Y)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Add A700, "X"s in columns 2 and 3.

21. Table D47

a. Relevant Conditions:

A55 C1 (Y)?

b. Modifications:

- Change A55 to A700, "X"s in columns 1 and 2.

22. Table D48

a. Relevant Conditions:

A55 C1 (Y) or C402 (Y)?

b. Modifications:

- Change A55 to A700, "X"s in columns 1 thru 4.

23. Table D49

a. Relevant Conditions:

NONE C74 (Y), C75 (3.), and C203 (5)?
NONE C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
A55 C1 (Y), C403 (Y), C404 (Y), C405 (Y), or
C410 (Y)?

b. Modifications:

- Change A55 to A700, "X"s in columns 2 thru 6.

24. Table D50

a. Relevant Conditions:

A58 C58 (15)?

b. Modifications:

- Change A58 to A700, with "X" in column 2.

25. Table D51

a. Relevant Conditions:

A57 C58 (15)?

b. Modifications:

- Change A57 to A700, with "X" in column 1.

26. Table D54

a. Relevant Conditions:

NONE   C406 (Y),   C410 (Y), or C414 (Y)?

b. Modifications:

- Add A700, "X"s in columns 1 thru 4.

27. Table D102

a. Relevant Conditions:

NONE	C602 (Y)?
NONE	C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
A56	C1 (Y) and C414 (Y)?
A54	C1 (Y)?

b. Modifications:

- Combine A54 & A56 to A700, "X"s in columns 1 thru 6.

28. Table D103

a. Relevant Conditions:

NONE	C415 (Y)?
A54	C1 (Y) and C414 (Y)?
NONE	C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Change A54 to A700, with "X" in column 2.

29. Table D104

a. Relevant Conditions:

NONE   C403 (Y), C404 (Y), C405 (Y), C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Add A700, "X"s in columns 1 thru 5.

30. **Table D105**

a. Relevant Conditions:

NONE	C403 (Y), C405 (Y), C414 (Y)

b. Modifications:

- Add A700, "X"s in columns 1 and 3.

31. **Table D106**

a. Relevant Conditions:

A54	C1 (Y) and C414 (Y)?
A56	C1 (Y) and C414 (Y)?
NONE	not C1 (Y) and C414 (Y)
NONE	C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Combine A54 & A56 to A700, "X"s in columns 1 thru 7.

32. **Table D107**

a. Relevant Conditions:

NONE	C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?
NONE	C403 (Y), C404 (Y), C405 (Y), or C410 (Y)?

b. Modifications:

- Add A700, "X"s in columns 1 thru 5.

33. **Table D109**

a. Relevant Conditions:

NONE	C1 (Y), C10 (1.5)

b. Modifications:

- Add A700, "X"s in columns 1 thru 4.

34. **Table D11[illegible]**

a. Relevant Conditions:

NONE	C37 (Y) and C415 (Y)
A54	C1 (Y) and C414 (Y)

A56   C1 (Y) and C414 (Y)
NONE   C409 (Y), C411 (Y), C412 (Y), or C413 (Y)?

b. Modifications:

- Combine A54 & A56 to A700, "X"s in columns 1 thru 9.

35. Table D117

a. Relevant Conditions:

A57   No X in any column.
A55   C1 (Y) and C403 (Y) or C405 (Y)?

b. Modifications:

- Combine A55 & A57 to A700, "X"s in columns 1 thru 8, except 6 (Note: there are No "X"s in any row of column 6).

APPENDIX C

SITUATION DEVELOPMENT

A. SITUATION 1

If either side has used chemicals and the other does not yet have chemical release, chemical release is requested. The action "REQUEST CHEMICAL RELEASE" can be an automatic release or can be an algorithm that tests whether using side's use of chemical has reached an established "chemicals free threshold" (e.g. the number of chemical attacks in the last 48 hours). If the threshold is reached, release should be scheduled to occur according to a reasonable estimate of the length of time it would take the request to go from the requestor to the command level which makes that decision and back to the requestor. An embellishment would be to have command level establish a release window rather than just a release. Another possible embellishment would be to modify the special munition decision table to revoke the release when one side's use of chemical falls below a similarly established "chemicals tight threshold". Note that the decision table continues to be scanned regardless of a match in this column.

B. SITUATION 2

This situation allows only the leading unit to request special munitions.

C. SITUATIONS 3, 4, & 5

These three situations have the same theme, approaching enemy reinforcements. The idea is to delay and degrade. To this end, all three request FASCAM. In addition, if the requesting unit is in MOPP 3 or 4, has chemical release, and the target unit is in a lessor MOPP level, then a chemical attack is requested. A further distinction is made to employ a persistent agent if the requesting unit is on the defensive (i.e., no forward movement). An embellishment would be to use persistent only if the requesting unit was going to be on the defensive for a length of time greater than the agent duration time. Note that the decision table continues to be scanned regardless of a match in these columns.

D. SITUATION 6

This situation allows only standard munitions to employed when the opposing forces are less than 300 meters apart. The implication is that there is no advantage to using special munitions in such close combat situations.

E. SITUATION 7 & 8

These situations have the requesting unit withdrawing opposed within direct fire weapon range. Requests for self screening smoke and self protecting FASCAM are made. In addition, situation 8 requests a persistent chemical attack if the requestor is in MOPP 3 or 4, the target unit is not, and the requestor has chemical release.

F. SITUATION 9 & 10

These situations have the requesting unit defending and not withdrawing opposed, within direct fire weapon range. Request for self protecting FASCAM is made. In addition, situation 10 requests a persistent chemical attack if the requestor is in MOPP 3 or 4, the target unit is not, and the requestor has chemical release. Smoke is specifically not requested because it would degrade the requesting unit's ability to employ direct fire weapons.

G. SITUATION 11 & 12

These situations have the requesting unit in pursuit of withdrawing target forces within direct fire weapons range. Requests for enemy blocking FASCAM and self screening smoke are made. In addition, situation 12 requests a non-persistent chemical attack if the requestor is in MOPP 3 or 4, the target unit is not, and the requestor has chemical release. Smoke is requested to reduce pursuing forces vulnerability.

H. SITUATION 13 & 14

These situations have the requesting unit on the offensive within direct fire weapons range. Request for enemy screening smoke is made. In addition, situation 14 requests a non-persistent chemical attack if the requestor is in MOPP 3 or 4, the target unit is not, and the requestor has chemical release. Smoke is requested to reduce the requestor's vulnerability while moving forward.

I. SITUATION 15 & 16

These situations are identical to situations 7 & 8, except the requestor is beyond direct fire weapons range. Requests are also identical. This makes these two columns redundant; they were included because this decision table is a direct translation of the flow chart in Figure III-3 (see Section III of the thesis main body).

J. SITUATION 17 & 18

These situations are identical to situations 9 & 10, except the requestor is beyond direct fire weapons range. Actions differ in that an additional request is made for enemy screening smoke. The intent is to keep the target unit screened from seeing the requestor (in his defensive positions) until the target unit has moved into direct fire weapons range.

K. SITUATION 19 & 20

These situations are identical to situations 11 & 12, except the requestor is beyond direct fire weapons range. Requests are also identical. This makes these two columns redundant; they were included because this decision table is a direct translation of the flow chart in Figure III-3 (see Section III of the thesis main body).

L. SITUATION 21 & 22

These situations are identical to situations 13 & 14, except the requestor is beyond direct fire weapons range. Requests are also identical. This makes these two columns redundant; they were included because this decision table is a direct translation of the flow chart in Figure III-3 (see Section III of the thesis main body).

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